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THE LOCALIZATION OF URANIUM AND THORIUM MINERALS IN POLISHED SECTION

PART 1: THE ALPHA RAY EMISSION PATTERN

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CONTENTS

Introduction 88
Autoradiographic mechanism 89
Properties of alpha particle emulsion 93
  Action of light 94
  Action of pseudophotographic agents 94
  Effect of pressure 94
  Chemical reactions with the emulsion 95
  Effect of beta and gamma radiations 95
  Effect of x-ray radiation 96
  Effect of neutron radiation 96
  Fading of the latent alpha ray image 96
  Effect of mercury vapor 97
  Effect of temperature during exposure 98
Preparation of the polished section 99
The autoradiographic exposure 101
Development of alpha particle emulsion 102
Resolving power of alpha ray pattern 102
Classification of uranium and thorium minerals 106
  Interference caused by samarium 114
Summary 115
Acknowledgments 116

ABSTRACT

Uranium and thorium minerals occurring in polished sections are characterized by means of a selective alpha ray emission pattern on light desensitized emulsions. The characteristics and special processing of the emulsion are described. Comparative studies reveal lack of sensitivity to beta and gamma radiations, visible and ultra violet light and chemical agents producing pseudophotographic effects. The emulsion is only slightly sensitive to x-rays and neutron radiations. The emulsions exhibit a marked fading of the latent image on delayed development, and the latent image is destroyed by the presence of mercury vapor during the exposure. The medium produces a sharply defined, reproducible image of alpha radiation originating from polished sections in direct contact with the emulsion. The resultant pattern can be enlarged up to 200 diameters and is serviceable in the identification of fine mineral grains and reveals the variation in the alpha ray activity of minute structures. The blackening is proportional to the number of alpha rays escaping from unit area of polished surface per second: $P_\alpha=\psi(30.1\ U+13.7\ Th)$, where ψ is the permeability of the mineral to alpha radiation and U and Th represent the quantity of uranium and thorium per gram of mineral. The radioactive minerals are classified into seven groups based on the relative photographic densities produced by the species compared with a unit of minerals of known alpha ray activity.

INTRODUCTION

Selective physical properties of matter are of considerable aid in the identification and localization of the components of a polished surface by means of analytical patterns (94). The autoradiographic pattern is of particular selectivity, as in naturally occurring substances a positive print is furnished only by the uranium and thorium minerals.[1] Shortly after the discovery by Henri Becquerel (5) that uranium compounds emitted radiations capable of penetrating black paper and rendering photographic emulsions developable, numerous investigations were reported on the photographic action of the uranium and thorium-bearing minerals. In 1900 Sir William Crookes (14) published a list of 16 minerals that activated the photographic plate and concluded: "after going through every mineral in my cabinet, a somewhat extensive collection, numbering many fine specimens" that only uranium and thorium bearing species gave the reaction. Similar studies were made by Pisani (72), who failing to interpose a black paper between the emulsion and the specimen, erroneously included wurtzite, fluorite and chlorophane in his list of radioactive minerals. These minerals are now known to be photoluminescent after excitation by sunlight, and the activation of the emulsion is caused by their persistent phosphorescence. Tables of the radioactive minerals, published by Bardet (4) and Wherry (91), were arranged in accordance with their relative photographic action, correlated with the uranium and thorium content. The autoradiographic technique is a well established tool in petrography and is employed extensively in the study of the homogeneity of specimens prior to analysis for age determinations (45).

[1] Isotopes of certain elements (potassium K^{40}, rubidium Rb^{87}, samarium Sm^{148}, and lutecium Lu^{176}) are also unstable and their spontaneous decomposition is likewise accompanied by radioactive radiations. K^{40}, Rb^{87}, and Lu^{176} give rise to beta radiation, and Sm^{148} is an alpha ray emitter. The intensity of these radiations in naturally occurring substances is very low and they can be detected photographically only by prolonging the exposure from several months to a year. By employing fast emulsions, a definite image is produced by uraninite after one hour's exposure. Hence, the potential interference of these feebly radioactive elements can be eliminated by proper control of the exposure.

The autoradiographic pattern has also been employed in studying the distribution of ingested naturally radioactive elements employed as tracers in animal tissue (6, 24, 47), in the orientation of minor radioactive constituents in crystals (34, 35), in the field of metallurgy (32, 84, 91), and in the study of radiocolloid aggregates (92). The technique has received considerable impetus since the discovery of methods for the synthesis of radioactive isotopes of elements of low atomic weight. Applications have been particularly numerous in the field of histochemistry with reference to the localization of ingested radioactive phosphorus (54), iodine (36), calcium and strontium (71). A new radiographic approach to the study of polished mineral surfaces has been described by Goodman (29, 30), in which certain constituents are rendered radioactive by neutron bombardment and the areas are subsequently localized by autoradiography.

In view of the numerous applications of the autoradiographic method, a systematic study of the technique was undertaken to define conditions for the rendition of a sharply defined pattern capable of sufficient magnification for the resolution of fine detail, and to investigate interferences with its specificity by other components in the section that are either photoluminescent or capable of producing pseudophotographic effects. Experiments with different types of plates revealed that for alpha ray emitters selective patterns can be obtained that permit the classification of uranium and thorium minerals according to alpha ray activity per unit area of (polished) surface. Since recent developments in the field of nuclear physics have given rise to renewed interest in the geochemistry of uranium and thorium, the working details of the alpha ray pattern are of timely interest to mineralogists and petrographers. The present work is confined to a description of the alpha ray pattern as a primary step in the determination of the presence of uranium and thorium in the polished section. Work is in progress on the further differentiation of the radioactive minerals by means of chemical patterns (94, 96) and will be published later.

AUTORADIOGRAPHIC MECHANISM

In the decay of uranium, thorium, and their radioactive equilibrium products, three distinct types of radiation are emitted, all of which are capable of activating photographic emulsions in varying degrees. According to Rutherford (74) the alpha, beta, and gamma rays produce in each case a marked action on the photographic plate, but owing to the difference in the absorption of these rays in the gelatin emulsion, it is difficult to make any quantitative comparison of their individual effects. Of the three radiations the alpha ray produces the most localized ionization, and Kinoshita (44) has demonstrated that in the case of the homogeneous alpha particles emitted from Radium C′ each particle produces a detectable photographic effect. However, the alpha particle has the shortest range and is stopped after traversing through about 30 microns of a silicate mineral. Most of the beta rays are absorbed in 5 mm. of aluminum or 1 mm. of lead and probably have an average range of 3 mm. in most silicate rocks. The gamma radiations are the most penetrating of all.

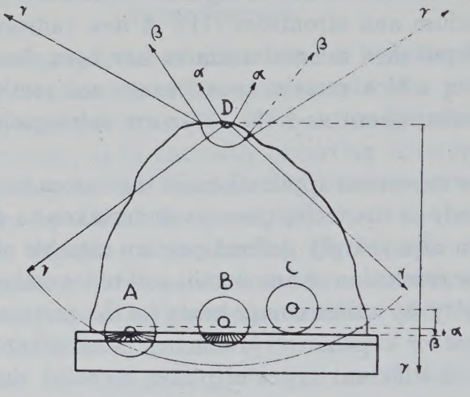

FIG. 1. Diagrammatic representation of relative photographic action of radioactive radiations on the normal type photographic emulsion.

The smallest circles represent the relative range of the alpha rays. The large circles about points A, B and C represent the active range of the beta radiation. The gamma rays originate from all parts of the mineral but are depicted only for the remote point D of the mineral.

The photographic action of the radiations is exhibited graphically in Fig. 1, showing a cross section of a massive radioactive mineral whose polished surface is in direct contact with the recording emulsion. The radiations are emitted in all directions, and each minute grain whose atoms are undergoing radioactive decomposition may be visualized as the center of a series of concentric spheres of radii equal to the range of the several radiations in the medium. Wherever these statistical spheres intersect the plane of the emulsion, the plate is rendered developable. A nucleus located directly on the polished surface, point A, will form a sharply defined image of a diameter equal to twice the range of the most penetrating alpha particle in the gelatin emulsion, accompanied by a diffuse image from the more penetrating but less active beta and gamma rays. Radioactive nuclei slightly beyond the range of the alpha particle in the mineral, points B to C, will contribute only to the fogging of the primary pattern, and a diffuse image will be recorded on some emulsions by the gamma radiation from the most remote nuclei, point D.

It is evident from these considerations that the autoradiographic print produced on an emulsion sensitive to all three radiations is not a true representation of the uranium and thorium content of the polished surface. In experimental practice, it is necessary with ordinary emulsions to interpose a sheet of black paper between the specimen and the plate in order to avoid activation of the emulsion by phosphorescent minerals and fogging of the plate from traces of vapor escaping from the mounting media, such as balsam, sealing wax, and to a lesser extent bakelite.[2] The black paper absorbs the greater part of the energy of the alpha particles and the diffuse image formed essentially by the beta and gamma radiations can no longer be interpreted as an analytical pattern of the polished surface.

To obtain a radiographic imprint which is a true representation of the uranium and thorium content of the surface, it is necessary to arrange the experimental conditions so that only the alpha rays reach the emulsion. Direct measurements of the range of alpha particles in uranium and thorium minerals are not available, but may be approximated with the aid of the Bragg-Kleeman stopping power rule (10) which states that the energy spent by an alpha particle in its passage through an elementary atomic matrix is proportional to the square root of the atomic weight. If a mineral be composed of atoms A, B, C · · · , in the relative proportions a, b, c · · · , then the range of a given alpha ray, R, is closely approximated by the expression:

$$R = \left[\frac{a\sqrt{W_A} + b\sqrt{W_B} + c\sqrt{W_C} + \cdots}{\rho}\right] k = \frac{\psi k}{\rho}\,. \tag{1}$$

In this equation W represents the atomic weight of the component atom, ρ the density of the mineral and k is a constant for an alpha ray of given origin. The factor ψ which varies with the chemical composition of the mineral, can be visualized as the permeability of the matrix to alpha radiation. For the alpha rays emitted by Ra C′, k can be evaluated from measurements of the radius of pleochroic haloes in biotite as recorded by Holmes (38) and is found equal to 0.00215 cm. The range in the solid of all other alpha particles originating from the disintegration of uranium, thorium, and their equilibrium products can then be estimated by multiplying k by the ratio of the range of the particular alpha ray in air to that of Ra C′ in air.

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[2] The literature on this subject is very extensive. Data pertinent to mounting media can be found in references 11, 13, 63, 73, 81, 85.

Table 1 shows the variation of range of the two most penetrating alpha rays, RaC′ and ThC′, in some of the more common uranium and thorium minerals, as evaluated from equation (1) using the air range data tabulated by Rutherford (74). These computations show that only those alpha rays emitted from nuclei located on the average less than 0.004 cm. above the polished surface can emerge and have sufficient residual energy to activate the emulsion. Any mechanism which can exclusively record this superficial layer of alpha ray activity will then provide a pattern closely approximating the composition of the polished surface.

TABLE 1. ALPHA RAY EMISSION FROM MORE COMMON URANIUM AND THORIUM MINERALS

Mineral	Avg. Sp. Gr.	Avg. ψ	Thickness of Active Section in microns		Escaping Rays, P_α per sq. cm. per sec.	
			Ra C′ ray	Th C′ ray	Max. P_α	Min. P_α
Uraninite	9.0	13.5	32	40	338	271
Bröggerite	9.0	13.2	32	40	273	244
Cleveite	7.5	12.5	36	45	229	207
Pitchblende*	7.0	12.5	38	—	278	246*
Thorianite	9.4	13.3	30	37	182	151
Gummite	5.1	11.5	49	—	238	171
Clarkeite	6.4	12.4	42	—	254	—
Curite	7.2	13.0	39	—	243	236
Carnotite	4.1	9.8	51	—	167	107
Torbernite	3.5	10.0	61	—	156	139
Uranophane	3.8	9.9	56	—	177	124
Uranothorite	5.3	9.7	39	48	102	60
Betafite	4.3	8.8	44	54	60	51
Samarskite	5.7	9.2	35	43	29	14
Pyrochlore	4.2	7.6	39	48	9	0
Microlite	6.4	10.2	34	42	12	0
Euxenite	5.2	8.7	36	45	23	6
Polycrase	5.0	8.3	36	45	27	16
Eschynite	5.2	8.8	—	45	19	12
Priorite	5.0	8.0	34	42	17	2
Monazite	5.1	9.2	—	48	16	7
Allanite	3.5	6.3	39	48	3	1

* These figures represent the constants of pure pitchblende. The more common crude ores are dispersions of the mineral in a siliceous matrix and the P_α of the system may run as low as 100 alpha rays per sq. cm. per sec. as indicated by Marble's analysis (55) of Great Bear Lake pitchblende.

An obvious approach to this mechanism is to prepare a parallel-faced slab of the specimen, slightly thicker than the range of the most penetrating alpha ray in the material. The photographic activity of the beta and gamma radiation from a section 100 microns thick is only a minor fraction of the total, and the developed image can then be interpreted as essentially an alpha ray pattern. This method, however, fails when a black paper is interposed between the surface and the emulsion, as any filter which stops luminous rays and prevents access of activating vapors will also absorb the greater part of the alpha rays.

A solution to this problem was found in the work of Blau (8) and Wambacher (90), who discovered that when silver halide emulsions were bathed in a solution of pinacryptol yellow they lost their sensitivity for visible light, beta, and gamma radiations, but could still be activated by impact with massive nuclear particles such as the alpha ray and the proton. The wide application of these special emulsions in the field of nuclear physics (79) led to the development of improved "alpha particle plates" by the photographic laboratories of both Ilford (93) and Eastman Kodak (20), and these plates are now available as regular commercial items. The Eastman fine grained alpha particle plate has been employed by Tyler and Marais (87) in the determination of the relative radioactivity of mineral grains by counting the number of alpha tracks developed about each particle embedded in the emulsion. More recently, Baranov and co-workers (3) have described the application of similar light desensitized thick-layered photographic emulsions in the distribution of traces of radioactive matter in carbonate and carbonaceous rocks. Trial autoradiographs with these emulsions showed that although a sharp image developed after contact with a polished section containing uranium and thorium minerals, the density was low and of poor reproducibility using the conditions of development recommended for the registration of individual alpha ray tracks. Further studies led to the method of development here described, which yields images of satisfactory density and reproducibility without destroying the specificity of the emulsion for alpha rays.

PROPERTIES OF ALPHA PARTICLE EMULSION

The Eastman alpha particle plates employed in these investigations consist of a thick layer of fine-grained silver halides desensitized to light. In order to absorb the high energy alpha rays emitted by Ra C′ and Th C′ impinging perpendicularly on the plate, the emulsion layer must have a thickness in excess of 50 microns. It is difficult to secure uniform development of these thick emulsions when the developing solution is kept at the customary temperature of 20°C. Neither altering the time of immersion, nor adding gelatin softeners to the developer gave reproducible autoradiographic images. After numerous trials, satisfactory results were obtained by simply warming the developing solution (Eastman D-19) to 32°C. At this elevated temperature, the latent image is rendered visible a few seconds after the plate is immersed into the bath and development is completed in two minutes. When the plates were developed at the standard temperature of 20°C., the densities of the images were very erratic on successive exposures to the identical source of alpha radiations. By developing at 32°C., the density of the image was reproducible on repeated trial, and was proportional to the exposure. By this unorthodox developing procedure, the emulsions were investigated for interferences with their specificity as recording media for alpha rays.

Action of Light:—The emulsions are remarkably insensitive to visible and ultraviolet light. Plates were covered with a coin and exposed at a distance of 10 feet for five minutes to the light from a 100 watt tungsten filament bulb and a cold quartz mercury vapor lamp. Only with the ultraviolet illumination did a faint fog develop on the area of the plate unprotected by the coin. Persistently phosphorescent minerals (antozonite, wurtzite) were excited to strong luminescence and placed in direct contact with the emulsion for periods varying between 5 minutes and 30 days. In no experiment was an image produced on development of the alpha particle plate. Under the same conditions of excitation, the specimens produced black images only after two minute periods of contact with *x*-ray or panchromatic emulsions (94).

Action of Pseudophotographic Agents:—An alpha ray plate was exposed to the vapors escaping from a 3% hydrogen peroxide solution for 30 minutes. No trace of blackening appeared on development. Under the same conditions, a deep black image developed when a contrast lantern slide emulsion was exposed to the vapors for an equal period. The traces of hydrogen peroxide formed by the oxidation of mounting media (bakelite, Wood's metal, montan wax) have no effect on the alpha ray emulsion even when the exposure is prolonged to 30 days. When the wooden contact camera is employed shortly after its preparation, the vapors arising from the sanded surface produce a very faint fog on the portions of the alpha ray emulsion not covered by the specimens. This effect is of diminishing intensity as the wood ages. Distinct pseudophotographic images caused by the mounting media are readily observable after 3 day exposures when using process or lantern slide emulsions as autoradiographic media.

Effect of Pressure:—Recent studies on the development of a latent image by pressure (2) on ordinary silver halide emulsions show that pressures of about 1000 kg. per sq. cm. must be employed to produce a measurable effect. When a polished surface is placed in contact with the emulsion, the weight of the specimen is uniformly distributed and the pressure at any given point of contact is low even when the specimen is clamped to the plate to prevent possible movement during exposure. Under the experimental conditions of exposure, no images were produced by direct contact of non-radioactive, polished specimens of equal weight and surface area.

Chemical Reactions with the Emulsion:—Since the polished surface of the specimen is in direct contact with the emulsion, the possibility of chemical reactions between certain minerals and the silver halides must be considered. A side reaction might arise between sulfide minerals and the silver salts in the emulsion. However, close examination of the plate after 30 day periods of contact with several common sulfide minerals (pyrite, chalcopyrite, chalcocite, pyrrhotite, pentlandite) and native sulfur showed complete absence of a brown image of silver sulfide. Mercury vapor will destroy the sensitivity of the emulsion to alpha radiations. However, native mercury is not known to occur with uranium or thorium ores.

Effect of Beta and Gamma Radiations:—In order to avoid long exposures in studying the properties of the fine-grain alpha particle emulsions, a more concentrated source of radiations than that afforded by uraninite was employed. This was prepared by dissolving 100 grams of uraninite in nitric acid and co-precipitating the radium onto about 200 mgs. of barium sulfate. This concentrate was deposited as a thin film on a brass disk and the emulsions were exposed to the radiations at a distance of 3 mm. from the film source. All quantitative measurements of photographic activity were made about two months after the preparation of the source in order to permit the radon to regain its normal equilibrium concentration.

Direct exposure to the source for 15 minutes produced an image with a photographic density of 0.10. When an aluminum foil of sufficient thickness to stop the alpha rays originating from RaC′ was interposed between the source and the emulsion, no image was produced after 24 hours exposure. This experiment showed that the plate was not activated by the beta and gamma radiations produced during the disintegration of radium and its equilibrium products. Further proof of the specificity of the emulsion for alpha rays was secured by exposing a series of four slabs cut from a single specimen of practically homogeneous uraninite. After polishing, the heights of these slabs were approximately 10, 5, 1 and 0.1 mm., respectively. On development, after a 100 hour period of exposure, the four images appeared to be equally black and subsequent measurement revealed only a maximum variation of 5 per cent in photographic density between the 10 mm. and the 0.1 mm. sections.

Effect of X-ray Radiation:—An alpha particle emulsion covered with a sheet of black paper was exposed for one hour to a beam of unfiltered *x*-rays generated from a copper target operating at 35,000 volts and 15 milliamperes. On development the image had a photographic density of 1.0. Using the normal *x*-ray emulsions a similar blackening is produced after 5–10 sec. exposure. This slight sensitivity of the alpha particle emulsion is of moment only in regard to its storage or exposure in proximity to *x*-ray machines. The spontaneous emission by minerals of radiations in the *x*-ray region has not yet been observed.

Effect of Neutron Radiation:—Alpha particle plates covered by black paper were exposed to slow and fast neutrons (together with the accompanying beta and gamma radiations) generated by the cyclotron at the Carnegie Institute of Washington. An exposure of 6 hours at an average current of 150 microamperes produced only a faint fog on the developed plates. Preliminary experiments indicate that boron and lithium can be localized in polished section by contacting the surface with an alpha ray emulsion and exposing the unit to neutrons. Both elements absorb neutrons with the selective reemission of alpha particles and these are recorded simultaneously by the emulsion.

Fading of the Latent Alpha Ray Image:—A very marked fading of the latent image was observed following delayed development in an effort to secure data on the relation between time of exposure and the photographic density. A polished specimen of uraninite was exposed against different portions of the same plate for periods of 1, 2, 5, 24, 48 and 377 hours. At the termination of the last exposure the plate was developed immediately after the removal of the specimen from its last position. Only two images appeared. A very dense one, corresponding to an exposure of 377 hours without delayed development, and a very faint image, corresponding to the region exposed for 48 hours and whose development was delayed for 377 hours, appeared. The remaining four portions of the plate showed no visible image. Exposures of 1 to 48 hours with the same specimen yielded distinctly visible radiographs of increasing density when the plates were developed immediately after the exposure.

To check this unusual phenomenon[3] a large sized alpha particle emulsion was cut into a series of test units. All strips received identical exposures except that development of one set was delayed. Table 2 shows that the 20 day delay resulted in almost complete loss of the image. Each test unit was developed individually in fresh portions of the same developer at the same temperature. Measurement of the density showed that in each case delayed development caused a diminution in the intensity of the alpha ray image and that a delay of 20 days resulted in its practically complete obliteration (Table 2).

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[3] According to Neblette (66) the latent image produced by light on ordinary photographic emulsions is extremely persistent and successful development of negatives 30 years after the exposure has been reported.

TABLE 2. FADING OF LATENT ALPHA RAY IMAGE

Photographic Density		Interval of Delayed Development	$(D_0-D_f)/D_0$
Undelayed D_0	Delayed D_f		
0.430	0.390	1 day	0.093
0.480	0.380	2	0.208
0.430	0.275	3	0.361
0.430	0.200	5	0.535
0.400	0.140	10	0.650
0.435	0.045	20	0.896

A survey of the literature revealed that this phenomenon had previously been observed by other investigators using fine-grained emulsions treated with pinacryptol yellow. Blau and Wambacher (9) state that after 14 days the density is half that produced on undelayed development. Lauda (51), who studied the effect in considerable detail, concludes that after a 160 day delay in development the loss in density is 80 per cent when the plate is stored under ambient conditions, 60 per cent when the emulsion is kept at 0°C., and only 8 per cent when the emulsion is kept in an evacuated desiccator.

This effect is of little moment in the practical application of the emulsions in autoradiography as development can be arranged to take place without appreciable delay. It raises the question, however, whether a fading effect occurs during long period exposure to weak alpha ray sources. Experiments with the same specimen, varying the time of exposure on individually developed plates result in images of progressively increasing density. Thus, a polished section of samarskite yielded images having photographic densities of 0.33 and 0.69 after exposures of 15 and 30 days, respectively. This indicates the absence of any pronounced fading of the latent image during prolonged exposure. It is difficult to reconcile the absence of a fading effect during prolonged exposure with the pronounced fading observed on delayed development.

Effect of Mercury Vapor:—In an effort to increase the sensitivity of the fine-grained alpha particle emulsion and thereby diminish the time of exposure for the registration of an image from feebly radioactive minerals, a globule of mercury was introduced in the box holding plate and specimen. Dersch and Dürr (18) have demonstrated that traces of mercury vapor hypersensitized panchromatic emulsions, causing an increase in speed of 75 to 150 per cent. For the alpha particle emulsion, the mercury vapor had the opposite effect, and no image appeared after development. Confirmatory evidence of the desensitization of the emulsion for alpha particles by mercury vapor was secured by supporting a plate for 40 hours in a jar containing a globule of mercury. A two hour exposure to the barium-radium sulfate source yielded on development a faint image having a photographic density of 0.02. A control plate, which did not come in contact with mercury vapor, gave the normal density of 0.43. In view of these observations, proper attention must be given to the storage of the fine-grained alpha particle plates. To avoid accidental access of vapor to the emulsion during long exposures, it is good practice to keep the specimen and plate in a desiccator.

Effect of Temperature During Exposure:—The intensity of the alpha ray pattern is not altered by small variations in temperature of the emulsion during the exposure. In one experiment the exposure (100 hours) was conducted in a refrigerator at 5°C. and the density of the plate was identical to that obtained at 25°C.

These studies show that the fine-grained alpha particle emulsion is a

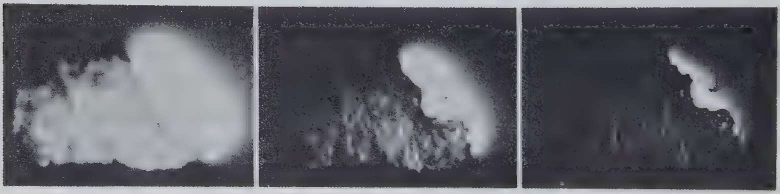

FIG. 2. Comparison of autoradiographs produced by different techniques.

Specimen is an unmounted slab of crytolite containing small inclusions of gummite and a layer of uraninite on extreme right. Sample collected at English Knob Mine, Spruce Pine, N. C., by F. A. Lewis. Prints A, B, and C were full sized positive prints of original negatives (reduced ½ in reproduction).

(*A*) Eastman type II-O spectrographic plate with layer of black paper interposed between emulsion and polished surface.

(*B*) Same emulsion as *A*, but black paper omitted. Better definition is secured, but pattern is not selective owing to potential actinic interferences.

(*C*) Eastman fine-grain alpha particle emulsion. The gummite inclusions are sharply defined and a non-radioactive inclusion in the uraninite is revealed. The faint halo about the uraninite region is caused by scattering of alpha rays from exposed inclined surface of the unmounted slab. In a mounted specimen this side radiation is completely absorbed by the casing.

highly selective medium for recording the distribution of alpha ray activity emanating from a polished mineral surface. The pattern is sharply defined since the penetrating beta and gamma radiations are not recorded on the emulsion. This is illustrated in Fig. 2 where the alpha ray pattern (print *C*) is compared with an autoradiograph (print *B*) on an emulsion sensitive to all three radioactive radiations. Since the fine-grained alpha particle emulsion is not activated by visible and ultraviolet light and not subject to pseudophotographic effects, there is no need for introducing a black paper filter to achieve specificity. The advantages in clarity and resolution gained by the elimination of the filter are evident by inspection of prints *A* and *C* of Fig. 2.

Preparation of the Polished Section

The standard method for preparing polished plane surfaces by moulding the specimen in bakelite is entirely satisfactory for use in obtaining the alpha ray pattern. Specimens composed essentially of radioactive minerals are usually friable and it is good practice to reinforce the massive sample with bakelite varnish or wax prior to cutting and mounting. Minerals in the metamict state have a tendency to shatter when mounted in bakelite at a temperature of 160°C. and 3000 lbs. per sq. inch pressure. This difficulty has been encountered with massive samples of samarskite and euxenite. Little if any fissuring occurs when these minerals are mounted in montan wax. The heat treatment inherent in these procedures probably causes the loss of some radon and thoron. Comparative alpha ray patterns of freshly mounted specimens and ones which have aged sufficiently since mounting for restoration of equilibrium with the gaseous emanations show but little variation in photographic density when the plates are examined visually. In one experiment designed to test the magnitude of this factor, the images produced by a freshly mounted crystal of thorianite and the same crystal exposed a month later showed a change in photographic density from 0.445 to 0.465. This 4.3 per cent increase is undoubtedly due to restoration of thoron and radon which were lost during mounting and polishing, as a completely equilibrated control section of uraninite exposed on the same plates for an equal period of time produced images varying in density by only 0.5 per cent. It is usually not practical to age the polished section prior to its autoradiography. However, a 5 per cent difference in photographic density is difficult to see, and as the group divisions differ by 30–50 per cent, this factor is not a serious detriment to the grouping by means of a set of equilibrated standards of the radioactive minerals minerals proposed in Table 3.

Bleached montan wax[4] is serviceable both as a binder and mounting medium for friable radioactive ores. This material melts at about 85°C. to a mobile liquid, which is rapidly absorbed by porous specimens, solidifies with little change of volume, and is sufficiently hard for dry polishing on emery papers. Unlike sealing wax, montan wax does not produce pseudophotographic effects and does not flow during spells of warm weather. Specimens prepared seven years ago show no evidence of deterioration. Satisfactory polished sections of extremely crumbly material, such as deposits of partially cemented carnotite on sandstone, have been prepared successfully by the following procedure.

Melt a sufficient quantity of wax in a 50 ml. beaker to cover the specimen, heat to about 110° C. and place beneath a bell jar. Apply suction until gases cease to escape from specimen. Remove the impregnated material while wax is molten and place on a small piece of flat board in a position oriented for cutting. Allow warm wax to drip onto the specimen until it is completely covered and cemented to the board. Cut into slabs, passing cutting wheel through board and specimen. Detach slices from support, wash and wipe dry. Center a selected slab beneath a plastic screw cap as described in Fig. 3 and place the assembled press on a warm hot plate until the wax surrounding the slab begins to melt. Remove from the hot plate, fill screw cap with molten wax and allow to cool to room temperature. Remove aluminum backing (*a*, Fig. 3) by warming momentarily on a hot plate. Polish on successively finer grades of metallographic emery papers, starting with grit no. 2 and finishing with no. 0000. Any abrasive adhering to the wax is removed by moistening the last sheet of paper and rubbing the specimen in the rouge slurry. If it is desired to preserve water soluble components, the wax can be cleaned by rubbing the surface against a sheet of blotting paper.

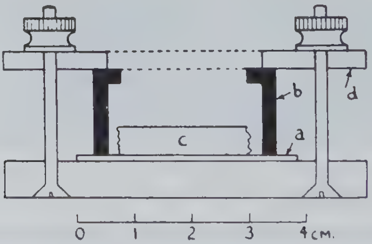

FIG. 3. Apparatus for mounting minerals in wax.

(*a*) Flat aluminum sheet about 1 mm. thick.
(*b*) Plastic shell container. A bakelite screw cap of suitable dimensions drilled with a 15 mm. hole may be employed, or the shell can be moulded to conform to standard size bakelite mountings.
(*c*) Slab of mineral impregnated with wax.
(*d*) Brass plate with hole in center for admission of molten wax.

[4] The supply of montan wax was originally obtained from the I. G. Farben Ind. and is no longer available. Domestic montan waxes exhibit a minute shrinkage on solidification, and while satisfactory as an impregnating medium, are not serviceable for mounting in screw caps. Halowax no. 2025 furnished by the Halowax Corp., N. Y. C., is satisfactory both as an impregnant and as a mounting medium.

Wood's metal of melting point 66°C. is also a satisfactory mounting medium in preparing specimens for autoradiography. It is much harder than montan wax and permits better polishing of the extreme edge of the specimen, particularly when the section contains hard ingredients. Wood's metal is attacked by etching media employed in contact printing, hence the use of this medium is limited to specimens to be employed solely as comparative standards for alpha ray activity.

After being mounted and polished, the specimen should be carefully washed with a moist piece of absorbent cotton to remove mineral dust embedded superficially on the mounting medium during the polishing process. Any linters adhering to the surface as a result of drying with soft tissue paper should be removed with a fine hair brush prior to making contact with the emulsion.

The Autoradiographic Exposure

The fine grained alpha particle emulsions are available in almost all of the standardized size photographic plates (20). The size of the plate selected should be considerably larger than the area of the specimen as the emulsion layer tends to thin out towards the edges of the plate and perfect contact with the polished surface can be effected only in the central flat portion. The mounted specimen and the annular ring containing embedded chips of known radioactive minerals are placed directly on the emulsion and both are clamped in position as shown in Fig. 4. The unit is wrapped in black photographic paper and stored in a desiccator.[5]

An exposure of 100 hours will suffice for the development of readily discernible images for minerals having a uranium content between 70 and 2 per cent. A smaller concentration of uranium and thorium can be localized by prolonging the period of contact. When the exposure exceeds 200 hours, the images produced by minerals of high alpha ray activity will be too black for accurate measurement of their photographic density. Hence, search for mineral grains of low alpha ray activity should be made on a separate plate, prolonging the exposure to 1000 hours.

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[5] The primary purpose of the desiccator is to avoid contamination by mercury vapor. It has been observed, however, that excessive humidity during the exposure causes a marked lowering in the density of the developed image. This is avoided by placing a dish of calcium chloride in the desiccator. The vessel should not be evacuated, as there is danger of disturbing the radon equilibrium, and the gelatin tends to peel from the glass backing when subject to prolonged reduced pressure.

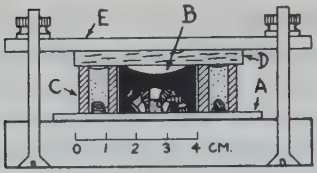

FIG. 4. Cross-section of autoradiographic camera.

(*A*) Fine grain alpha particle plate resting on wooden base.
(*B*) Mounted specimen.
(*C*) Annular lucite ring drilled with 7 holes, 5 mm. in diameter, in which are embedded chips of radioactive minerals of known alpha ray activity.
(*D*) Cotton or felt pad for equalizing pressure.
(*E*) Clamping board preventing movement of specimens during exposure.

DEVELOPMENT OF ALPHA PARTICLE EMULSION

Except for the extraordinary temperature of the developing bath, the photographic processing of the alpha particle emulsion is similar to that of light sensitive plates or films. Insoluble particles are readily embedded in the gelatin film and interfere with the subsequent photomicrography of the alpha ray pattern. Hence all solutions and wash waters coming in contact with the emulsion should be filtered, and the plate finally dried in an atmosphere reasonably free from dust.

A clean glass tray is preheated in a stream of warm water adjusted to about 32° C. A freshly filtered portion of developing solution D-19 of sufficient volume to cover the plate is likewise warmed to 32° C. Remove the plate from contact camera, place in a tray, cover with developer solution and rock the dish for two minutes. Pour off developer and discard, introduce about 100 ml. of distilled water at 25° C., directing the stream against the walls of tray and discard after rinsing plate for about 30 seconds. Treat the plate with about 50 ml. of Eastman Tropical Hardener SB-4 keeping the tray in motion for about one minute and then continuing the hardening process for another two minutes with solution remaining quiescent. Discard hardening solution and introduce about 50 ml. of freshly filtered fixing solution, formula F-5. Complete solution of the silver halides is usually effected in 15 minutes; longer periods of fixation do not harm the emulsion. Wash the plate in a stream of filtered tap water for about two hours.

RESOLVING POWER OF ALPHA RAY PATTERN

The radiographic image developed on the fine grain alpha particle plate is sharply defined and is capable of considerable magnification. Examination of Fig. 5 shows that only those radioactive nuclei located on the polished surface and the immediate thin layer defined by the range in the mineral of the most penetrating alpha ray will register an image on the emulsion. Grains of uranium and thorium minerals as small as 20 microns diameter are readily detected when embedded in a non-radioactive matrix by examining the pattern by transmitted light at a magnification of 100 diameters. These minute grains are readily differentiated by a surrounding halo of alpha particle tracks from opaque dust specks that occasionally contaminate the processed emulsion. The pattern provided by a radioactive grain of finite dimensions consists of a series of alpha particle tracks, the greater number of which are oriented at right angles to the emulsion layer. A small fraction of the alpha rays, originating from nuclei near the extreme edges of the grain, strike the emulsion laterally and their trajectories are recorded by the emulsion as individually resolvable tracks.

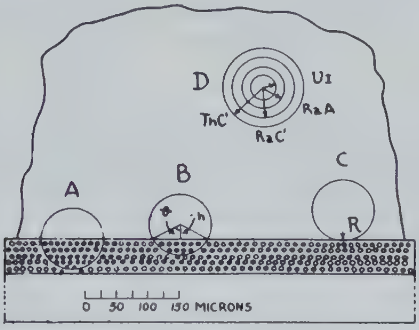

FIG. 5. Diagrammatic representation of action of alpha rays on emulsions desensitized to beta and gamma radiations.

Radii of circles about point *D* represent relative ranges of different alpha rays which may be ejected from any point in the mineral. The radii of circles, *A*, *B* and *C* represent the range of the most penetrating ray at different levels above the polished surface. In the illustration the permeability to alpha rays is the same for both the mineral and the emulsion. A latent image is produced wherever rays penetrate the emulsion.

Measurements by Wilkins (92) of the range of alpha particles in silver halide gelatin emulsions show that the stopping power of the recording medium is 1300 times as great as that of air. Alpha rays emitted by RaC′ and ThC′ will therefore have a range in the emulsion of 53 and 66 microns, respectively. A point source of alpha ray activity in direct contact with the plate will generate a hemisphere of individual tracks in the emulsion which may attain a maximum radius of 66 microns. Since the emulsion is observed in a plane at right angles to the optic axis of the microscope, only the horizontal projection of the tracks is observed. In general, the visual annulus of diffusion about the image of the grain is less than the maximum range of the most penetrating alpha particle. The horizontal projection of rays impinging into the emulsion at the median angle of 45° is equal to $R/\sqrt{2}$, which is equal to 38 and 47 microns for alpha particles ejected from RaC′ and ThC′, respectively.

Comparative microscopic measurements of the dimensions of mineral grains on the polished surface and their corresponding alpha ray patterns show that the width of the diffuse annulus varies between 30 and 40 microns. A sample of calcite from Joachimsthal, Bohemia, containing minute inclusions of pitchblende, proved a serviceable test specimen for measuring the diffuseness in the image caused by the lateral alpha rays.

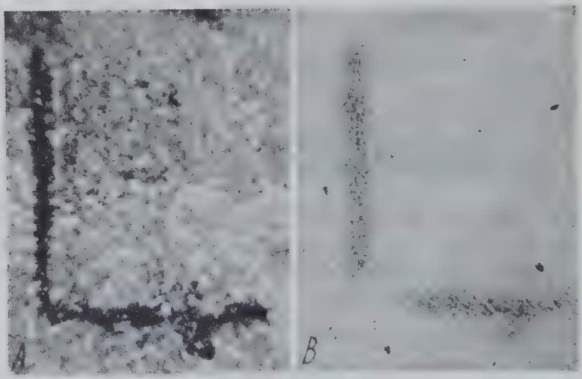

FIG. 6. Resolving power of alpha ray pattern.

Comparative photomicrographs at 100× (reduced ½ in reproduction) of a pitchblende inclusion in a non-radioactive matrix. Sample collected by Charles R. Toothaker at Joachimsthal, Bohemia.

(*A*) Polished section under oblique illumination.

(*B*) Alpha ray pattern under transmitted axial illumination.

Figure 6 reproduces one of the minute radioactive inclusions, *A*, and its corresponding alpha ray pattern, *B*, at 100 diameters magnification. The width of the angular inclusion measures 10 microns; at the same point, the radiographic image averages 70 microns. This corresponds to a lateral alpha ray diffusion of 30 microns on each side of the image proper, in close agreement with the theoretical deductions. This factor also causes an apparent diminution in the dimensions of non-radioactive inclusions in matrices of uranium and thorium bearing minerals which must be taken into consideration when the foreign bodies are very minute. Thus, a gangue vein less than 60 microns wide may appear to be feebly radioactive as a result of scattered alpha rays from the surrounding matrix.

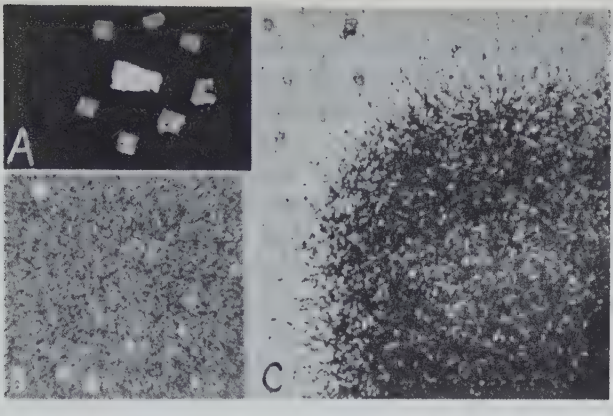

FIG. 7. Successive stages in the magnification of an alpha ray pattern.

(*A*) Group of thorianite crystals from Bambaraluma Valley, Ceylon (U. S. National Museum no. 94346) surrounding a central chip of uraninite from Katanga, Belgium Congo. Full sized positive print from pattern.

(*B*) Photomicrograph at 20× of alpha ray pattern of an entire crystal showing non-radioactive inclusions.

(*C*) Corner of thorianite cube at 200× (reduced $\frac{1}{3}$ in reproduction) showing some alpha ray tracks which struck the emulsion at glancing incidence.

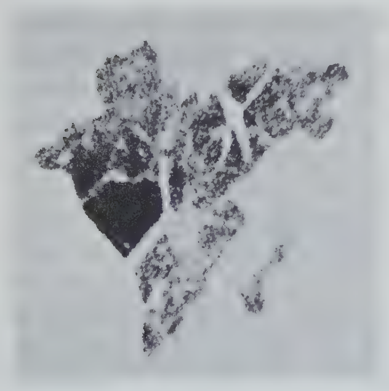

FIG. 8

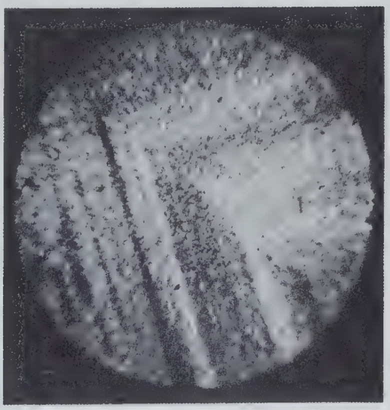

FIG. 9

FIG. 8. Photomicrograph at 20× (reduced $\frac{1}{3}$ in reproduction) from alpha ray pattern of an altered thorianite. Sample collected by A. Rosenzweig at Easton, Pa.

FIG. 9. Alpha ray pattern, enlarged 15× (reduced $\frac{1}{3}$ in reproduction) of section of samarskite from Mitchell Co., N. C. Sample no. 1849 of Brush Mineral Collection.

Although it has these limitations, the alpha ray pattern is still capable of yielding images of radioactive minerals which provide serviceable information concerning the relative concentration and distribution of alpha ray activity on successive magnification up to about 200 diameters. Figure 7 (*A*) reproduces the alpha ray pattern of a group of thorianite crystals which, considered as a macro print, shows the uniform distribution of uranium and thorium in the crystals, and that their alpha ray activity is less than the central chip of uraninite. A photomicrograph of one of the crystals at 20× magnification, Fig. 7 (*B*), shows the presence of minute non-radioactive inclusions. Further magnification of a corner of the alpha ray pattern reveals the scattered alpha ray tracks ejected from the edges of the cubic crystal. In contrast to the uniform distribution of uranium and thorium in the Ceylon thorianite, an alpha ray pattern of thorianite from Easton, Pa., Fig. 8, shows a considerable variation in alpha ray activity corresponding to graded zones of alteration evident on examination of the polished section.

The excellent resolving power of the fine grain alpha ray emulsion[6] permits the sharp delineation of variations in the spatial distribution of uranium and thorium along the crystallographic axes of crystals that appear to be optically homogeneous. A striking example of this varied deposition is furnished by an alpha ray pattern, Fig. 9, of a mounted section of samarskite. Assuming a linear proportionality between the alpha ray activity and photographic density in the image, a variation of 3 per cent uranium (and thorium) is exhibited between the zones of maximum and minimum blackening. This phenomenon is recorded vaguely on light sensitive photographic plates and only idealized sketches from such autoradiographs have been capable of reproduction in the past (25).

Classification of Uranium and Thorium Minerals According to Alpha-Ray Activity

Radiometric methods of analysis have been applied in the classification of radioactive minerals. By comparing the activity of the powdered mineral and a similar layer of uranium oxide Goldschmidt (28), employing a gold leaf electroscope, observed an approximately linear relationship between the measured activity and the theoretical alpha ray activity that can be calculated from the uranium and thorium content with the aid of the rule[7] formulated by McCoy and Ross (58). The blackening produced on a photographic plate is also a measure of the relative radioactivity and this lends itself to the identification of radioactive inclusions. The variation in photographic density is sufficiently marked, even in the case of emulsions responding to beta radiations, so that minerals in which uranium and thorium are principal components can be differentiated readily from species in which these elements occur only as minor constituents. As a type example of such application may be cited the identification by Goddard and Glass (27) of grains of uraninite in a feebly radioactive cerite. Since the emulsion under consideration is a highly selective recording medium for alpha particles, investigations were conducted to test its suitability as a quantitative tool for recording the number of alpha particles escaping from a polished surface of a radioactive mineral.

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[6] According to Mees (59) the resolving power of photographic plates for optical images ranges between 18 to 30 microns depending upon the speed of the emulsion. The resolution of this contact process is of the same order of magnitude.

The photographic density of the alpha ray pattern is a measure of the number of particles which entered the emulsion during the period of exposure. For mineral species sufficiently old for the attainment of radioactive equilibrium, the number of alpha particles escaping through the polished surface is proportional to the uranium and thorium content and provides a convenient index for the analytical grouping of the radioactive minerals. Unlike the complex ionization produced by an alpha particle at different points of its range through air,[8] the photographic action on silver halide grains is uniform throughout the path of the alpha ray and the photographic density is directly proportional to its range in the emulsion (44). Hence, an approximately linear function is to be expected between the photographic density, $D = \log$ (incident light/transmitted light) of an alpha ray pattern and the number of particles striking a unit area of the emulsion per unit of time, P_α.

The exact evaluation of the number of alpha particles producing the blackening is a problem of considerable difficulty owing both to the variation in range of rays produced by the numerous members of the uranium, actinium and thorium series and to the loss of part of their energy in traversing the mineral before they strike the emulsion. An approximate solution is secured by assuming that the ejection of all particles from a given point is equally probable and that the disintegration of each series can be represented by a single hypothetical particle having a range, $\overline{R}_{\mathrm{U}}$, $\overline{R}_{\mathrm{Th}}$, which is equal to the arithmetical mean of the ranges of the several members of the uranium and thorium series, as expressed by equations (2) and (3)

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[7] When the unit of activity is that due to 1 sq. cm. of a thick film of U_3O_8, then the radioactivity, as measured by the electroscope, of any mineral which is sufficiently old for the establishment of radioactive equilibrium is expressed by $3280U+953Th$, where the respective symbols refer to the weight of uranium and thorium present in 1 gram of the mineral.

[8] The early work of McCoy and Leman (56) on the ionization produced by alpha rays showed that the number of ion pairs generated by the passage of an alpha ray through air is proportional to the $\frac{2}{3}$ power of its range, The more recent treatment of the problem by Evans (22) and Goodman and Evans (23) shows that the total ionization above a thick solid emitting alpha particles is only approximated by the $\frac{2}{3}$ power rule in the limiting case of very long range rays.

$$(2)\quad \overline{R}_{\mathrm{U}} = [R_{\mathrm{U_I}} + R_{\mathrm{U_{II}}} + R_{\mathrm{Io}} + R_{\mathrm{Ra}} + R_{\mathrm{Rn}} + R_{\mathrm{RaA}} + R_{\mathrm{RaC'}} + R_{\mathrm{RaF}}]/8 = 4.04 \text{ air cm.}$$

$$(3)\quad \overline{R}_{\mathrm{Th}} = [R_{\mathrm{Th}} + R_{\mathrm{RdTh}} + R_{\mathrm{ThX}} + R_{\mathrm{Tn}} + R_{\mathrm{ThA}} + R_{\mathrm{ThC'}}]/6 = 5.11 \text{ air cm.}$$

According to the measurements of Rutherford and Geiger (75) the total number of alpha particles emitted by a mineral containing 1 gram of uranium in equilibrium with its disintegration products is 9.67×10^4 per sec.[9] The corresponding number emitted by 1 gram of thorium in equilibrium with its disintegration products is $0.36 \times 9.67 \times 10^4 = 3.48 \times 10^4$ per sec. The number of alpha particles generated, N_g, in a thin slab of mineral of density ρ defined by 1 sq. cm. of the polished surface and the range of the average alpha rays is then expressed by the summation of equations (4) and (5) in which the symbols U and Th represent the weight of uranium and thorium per gram of mineral.

$$(4)\qquad N_g^{\mathrm{U}} = \overline{R}_{\mathrm{U}} \rho \mathrm{U} \times 9.67 \times 10^4$$

$$(5)\qquad N_g^{\mathrm{Th}} = \overline{R}_{\mathrm{Th}} \rho \mathrm{Th} \times 3.48 \times 10^4$$

Substituting expression (1) for the range[10] of an alpha particle in a solid, yields:

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[9] This value includes the number of alpha particles formed during the disintegration of the actinium series. The studies of von Grosse (89) show that the activity ratio of actinium to the uranium-radium series is 4:100. In view of the small number of actinium alpha rays generated in the thin section, but little error is introduced by assigning the same value for the average range of the hypothetical alpha particle to both the uranium and actinium series.

[10] The range as calculated from the Bragg-Kleeman rule must be considered only as a rough approximation when dealing with the complex minerals represented by the multiple oxides. Specimens like samarskite contain as many as 36 individual atomic species (counting all members of the rare earth group), and though the rule yields values in close agreement with experimental measurements in the case of elementary metals and relatively simple mixtures of gases, it is problematical whether it is equally applicable to the more complex uranium and thorium minerals. In evaluating the permeability by means of equation (1) minor constituents of low atomic weight were not tallied individually to simplify the labor of computation. Their contribution to the stopping power is relatively minute and their elimination causes only a small increase in the atomic oxygen count which is obtained by difference after the major atomic units are computed.

$$N_g{}^U = \psi U \left(0.00215 \times \frac{4.04}{6.97}\right) 9.67 \times 10^4 = 120.5\psi U \tag{6}$$

$$N_g{}^{Th} = \psi Th \left(0.00215 \times \frac{5.11}{6.97}\right) 3.48 \times 10^4 = 54.8\psi Th \tag{7}$$

$$N_g = N_g{}^U + N_g{}^{Th} = \psi(120.5U + 54.6Th). \tag{8}$$

Only a small fraction of the alpha particles generated in the effective thin section are capable of striking the emulsion. The particles are ejected at random and statistically one-half the number generated will be directed away from the emulsion. Study of grain *B* in Fig. 5 reveals that of the remaining number headed towards the emulsion only those rays subtended by the solid angle formed by the rotation of 2θ will be capable of reaching the polished surface. A formal mathematical treatment of the number of alpha particles escaping through a solid surface by Evans (22) shows that only one-fourth of all alpha rays generated will escape through the polished surface. Hence, the photographic density of the image may be expected to be proportionate to a value P_α representing the number of alpha particles which escape per second from 1 sq. cm. of polished mineral surface.

$$P_\alpha = N_g/4 = \psi(30.1U + 13.7Th) \tag{9}$$

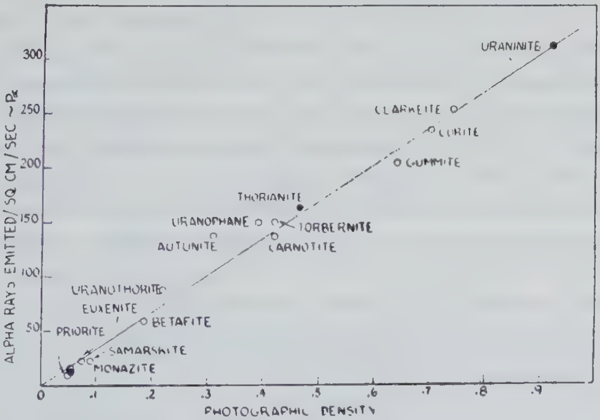

FIG. 10. Graph showing the relationship between the photographic density of the pattern and the number of alpha rays striking the emulsion.

To test the validity of this equation, a series of polished sections containing homogeneous chips of minerals of varying uranium and thorium content was exposed against a fine grain alpha particle emulsion for 115 hours and the photographic density of the developed images were measured by means of a recording microdensitometer. The results of this experiment are plotted in Fig. 10. Using the same specimens, exposure time, and conditions of development, repeated experiments showed that the densities of the images are reproducible on different plates within an error of 1 per cent when the photographic density is about 1.0, and about 10 per cent for faint images ($D=0.1$). The solid circles represent minerals whose uranium and thorium content was determined by the author on portions of the specimen adjoining the material from which the polished sections were prepared. The P_α values assigned to these minerals, uraninite 313, thorianite 164, and monazite 14.2 probably correspond closely to the alpha ray activity exhibited by the corresponding polished sections. Points ⊙ represent minerals whose P_α value was computed from analyses recorded in the literature on specimens from the same locality as the chips selected for study. These values are not as reliable as those based on direct analysis, as the chips studied may not in all cases be representative of the material originally selected for analysis. In general, the curve shows a direct proportionality between the photographic density of the image and the alpha ray activity computed from equation (9) over a wide range of uranium and thorium contents. The departure from exact linearity is well within the range of uncertainty in the evaluation of P_α and the measurement of the photographic density. A contributory factor in the more marked deviations of autunite (23.9 per cent), uranophane (8.7 per cent), and uranothorite (17 per cent) is the non-attainment of radioactive equilibrium. Studies by Gleditsch on Norwegian uranothorites show that the ratio of radium to uranium in this mineral is usually lower than the equilibrium amount (26).

The linear relationship[11] between the photographic density and the alpha ray activity of the polished surface permits the classification of the uranium and thorium minerals in accordance with their relative P_α values and presents a simple means for their qualitative grouping as an aid for their identification. The known uranium and thorium minerals can be segregated into seven groups on the basis of their relative alpha ray activity. The members of these groups are listed in Table 3 in the order of their average P_α values as computed from their chemical composition.[12] The variation of uranium and thorium contents within a mineral species is in several cases sufficiently wide to cause overlapping into more than one group; such minerals are listed under both groupings. A considerable number of the minerals listed represents species of very rare occurrence and the evaluation of the P_α value is based only on a single analysis of the material from the type locality.

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[11] The data presented in Fig. 10 do not prove the absolute validity of the coefficients in eq. (9) as these are based on a series of simplifying assumptions. In order to check these calculated values, the number of alpha particles escaping from the polished surface was counted by observing the scintillations on a zinc sulfide screen placed over a fixed area of the mineral. These counts were considerably lower than the P_α calculated for the mineral. The observed count was about 15 per cent of the theoretical for uranium minerals, and about 25 per cent for minerals whose activity was due chiefly to thorium isotopes. The direct counting of scintillations is very difficult, particularly for an observer with little experience in the technique, and the eye is probably able to detect only the brilliant flashes caused by the more energetic RaC′ and ThC′ rays, so that the more abundant short ranged particles escape detection. This is confirmed by the higher count on thorium minerals whose alpha rays are more energetic than those produced in the uranium series. The uncertainty in the absolute values of P_α does not invalidate the proposed classification as any change in the value of the coefficients will be consistent for all minerals in the tabulation.

In practice, the mounted specimen is surrounded by an annulus, Fig. 4, in which are embedded chips of known minerals whose P_α is representative of the group. The two units are exposed simultaneously for 100 hours and the developed plate is examined in a uniform field of transmitted light. Interposing an opal glass between the plate and the light source facilitates the observation of very weak images. Under these conditions of illumination, 20 per cent variations in photographic density are easily discernible. The intensity of radioactive inclusions revealed by the pattern is compared visually with the surrounding images produced by the standard chips and a group number is assigned to the unknown constituents. In making such visual comparisons the images should be masked so that nearly equal areas of the standard and unknown patterns are exposed to view in order to avoid fallacious interpretations of density due to marked inequality in the size of the patterns. When the density falls on the borderline of two standards, the grouping of greater alpha ray activity should be assigned in order to compensate for the small loss of radon or thoron incurred during the mounting and polishing of the specimen. A plate of this character, showing a polished section containing radioactive inclusions and the surrounding alpha ray patterns of the standards, is reproduced in Fig. 11. Minerals belonging to group *G* have a very low uranium and thorium content and do not produce a discernible image after 100 hours exposure. If such species are suspected from the behavior of the massive material towards an electroscope or a Geiger counter, the polished section must be exposed from 250 to 1000 hours in order to secure an image of suitable density for the localization of the individual radioactive grains.

[12] The analyses of the minerals investigated were selected chiefly from the tabulations in Dana's "System of Mineralogy" (15, 70), Doelter's "Handbuch der Mineralchemie" (19) and the analytical data listed by Holmes (38) in his studies on the age of the earth. Table 3 also includes all new species and varieties of uranium and thorium minerals that have been described since 1931, the date of the last comprehensive listing of the radioactive minerals (38).

The tabulation does not include minerals which only occasionally occur with appreciable amounts of uranium. Among these may be mentioned a garnet-like mineral from Argentina (38) carrying 0.4 per cent U_3O_8 and an iron-lime garnet from Hybla, Ontario, found by Ellsworth (21) to exhibit a weak radioactivity. Ellsworth also describes two alteration products of thorite, a white mineral alpha-hyblite and a yellow brown variety, beta-hyblite, which appear to be hydrous, basic sulphosilicates of thorium. Lack of analytical data prevents the listing of davidite which appears to be a mixture of several minerals and whose radioactivity may be due to the carnotite observed to be present (70). Northrop (67) lists an unnamed thorium mineral from Harding Mine district, New Mexico, with 32.35 per cent thorium and 0.185 per cent uranium which is probably a member of group *E*. The unnamed multiple oxides of ZrO_2-TiO_2-ThO_2 descbried by Blake and Smith (70, p. 741) have a computed P_α of 23–28 for the thorian members.

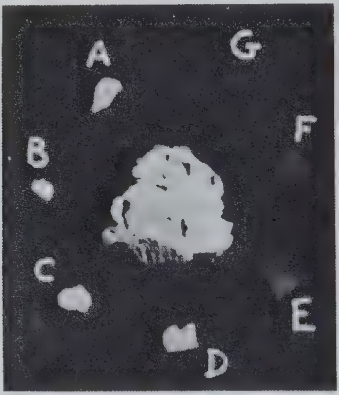

Fig. 11. Positive print from alpha ray pattern of a uranium ore and surrounding radioactive mineral standards.

(*A*) uraninite; (*B*) thorianite; (*C*) torbernite; (*D*) uranothorite; (*E*) samarskite; (*F*) monazite; (*G*) microlite.

The contrast on the alpha ray plate is greater than that exhibited in positive print reproduction.

This method of classification is applicable whenever the mineral is sufficiently old for the attainment of radioactive equilibrium. This condition is attained when the age of the mineral exceeds 1,000,000 years. However, if an overall error of 10 per cent is allowed in the estimation of P_α and the measurement of the photographic density then minerals only 250,000 years old will produce sufficient alpha radiation necessary for the production of an image whose density approximates that stipulated by equation (9). In a study of about 200 polished samples of uranium and thorium minerals, representing 41 species, only two specimens were observed for which the density of the alpha ray image differed radically from the theoretical alpha ray activity, P_α. Coatings of autunite on feldspar, from Spruce Pine, N. C., failed to give an alpha ray pattern after an exposure of 500 hours.[13] The other exception is thorotungstite (78), which failed to produce an image after 1000 hours' exposure. Both minerals are probably of very recent origin.

Another factor which must be considered in the evaluation of the alpha ray pattern is the possibility that in the preparation of the section the cutting wheel intersected the mineral grain at an extreme edge, leaving a thickness of material behind the exposed face less than the range of the most penetrating alpha ray in the mineral. Under these circumstances, which become more probable the smaller the grain size of the inclusions, the image will be less intense than that stipulated by theory. It is noteworthy that P_α is a rather unusual physical property, embodying extensive as well as intensive functions. The P_α remains constant and is independent of the thickness of the specimen provided it exceeds a minimum thickness of about 30–60 microns. When the grain size falls below this limiting thickness, P_α no longer characterizes the mineral. This difficulty is encountered when very fine grains are dispersed uniformly in an inert matrix. Thus, most analyses of pure pitchblende lead to a P_α value of 278–246. The crude ore, however, may contain about 30 per cent silica or clay which dilutes the alpha ray activity per unit area and results in an image of lower photographic density. Occurrences of pitchblende in which the grain size of the pure mineral is smaller than the critical grain size are allocated to groups *B* and *C*.

Alteration and the partial leaching of radium will give rise to variation in alpha ray activity of the resultant mineral. Such conditions have been described by Lind (53) in the sampling of carnotite ores for electroscopic assay; and the presence of radium in excess of the amount in radioactive equilibrium with uranium has been demonstrated by Kurbatov (46) in different portions of tyuyamunite. The leaching of radium from a primary mineral and its redeposition along the outer border of the alteration product is frequently observed in nodules of gummite (Fig. 12). The exposed radium is brought into solution by percolating waters and may again be deposited when the solution comes in contact with lead or barium minerals capable of adsorbing radium sulfate. This phenomenon gives rise to minerals with an alpha ray activity in the absence of uranium or thorium. A radioactive pyromorphite from Isay l' Eveque, France, has been reported by Danne (16) and the activity was shown to be a surface adsorption phenomenon by McCoy (57). Another sample of pyromorphite from Gennammari, Sardinia, has been described by Misciatelli (62) as having an activity equivalent to 0.0028 grams of U_3O_8 with chemically detectable amounts of uranium or thorium absent. Likewise, radioactive barite from Carlsbad in which the activity is derived from adsorbed radium have been analyzed by Haberlandt (33).

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[13] Massive samples of the mineral from Autum, France, and Mt. Painter, S. Australia, furnished an alpha ray pattern of density proportional to the P_α range of autunite.

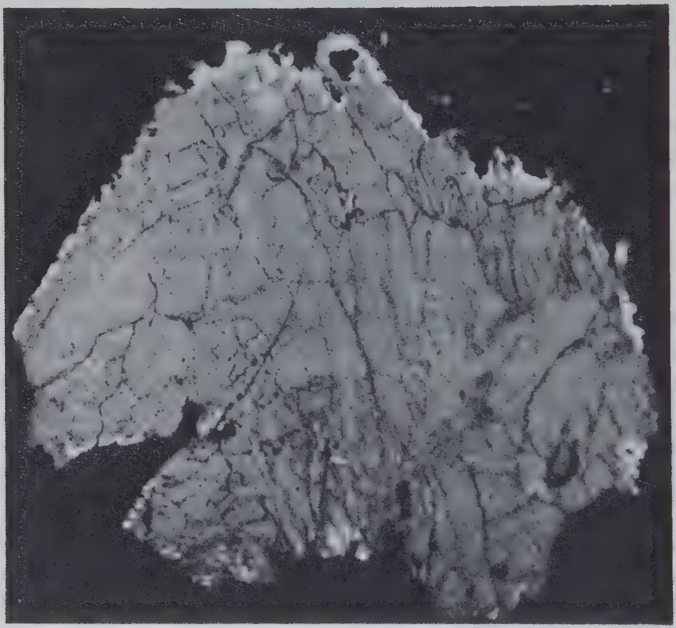

FIG. 12. Alpha ray pattern, enlarged 7× (reduced $\frac{1}{3}$ in reproduction) of complete cross-section of a gummite nodule. Sample collected at the English Knob Mine, Spruce Pine, N. C., by F. A. Lewis. The white areas correspond to regions of high alpha ray activity.

Interference by Samarium: As noted in the introduction, Sm^{148} emits alpha rays, and its potential interference must be considered as it is present in those uranium and thorium minerals that contain the rare earth oxides. The element emits 150 alpha rays per sec. per gram having a range of 1.28 cm. in air (23). In a mineral containing little uranium and thorium and about 10 per cent samarium, there is a possibility that the activity of the samarium contributes appreciably to the density of the alpha ray pattern. Calculations based on the permeability of allanite to the alpha particle emitted by samarium show that the number of rays

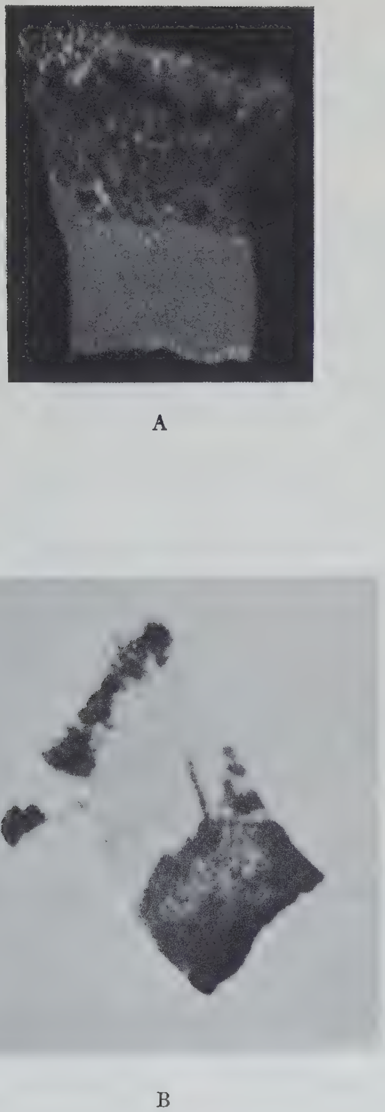

FIG. 13. Plates, showing variation in alpha ray activity of secondary uranium minerals from the Katanga, Belgium Congo deposits.

(*A*) Polished section, oblique illumination, 10×. Uppermost layer, curite; center, torbernite; bottom, gummite.

(*B*) Alpha ray pattern, axial illumination, 10×.

contributed is only 0.009 per sq. cm. per sec., whereas the P_α due to uranium and thorium present ranges between 1 and 2.6. With increase in the P_α value of the mineral the contribution of the samarium alpha rays becomes entirely negligible. The samarium contributes about 0.5 per cent to the alpha ray pattern of allanite, 0.05 per cent to that of samarskite and only 0.001 per cent to that of cleveite.

These are of rare occurrence and for most samples the classification has proven of utility as a first step towards the identification of radioactive inclusions. The variation in alpha ray activity corresponding to different mineral species occurring in close association is illustrated by the complex alteration products of uraninite characteristic of the Belgian Congo deposits, a study of which is presented in Fig. 13. At the present writing, mineralographic description of opaque uranium and thorium minerals is entirely lacking except for a brief description of uraninite by Schneiderhöhn (77) and Short (80). The petrographer must therefore adapt the descriptions available in the literature for massive material to interpretation of microscopic observations, or preferably compare the surface under study with polished sections of known material. It is difficult to obtain authentic samples of the less common species. Optical data for the better defined uranium and thorium minerals are recorded by Larsen and Berman (49).

Work is in progress directed towards the further identification of the radioactive mineral species by means of hardness tests, color of the micro streak,[14] fluorescence under ultraviolet light, and the localization of constituent metals and radical groupings by chemical printing techniques (96).

SUMMARY

The complex group of uranium and thorium minerals is characterized by the production of a selective alpha ray pattern on a photographic emulsion desensitized to light. The relative intensity of the image permits the subdivision of the radioactive minerals into a series of seven groups as a preliminary step towards their identification in polished section. The emulsion has been studied intensively with respect to its behavior towards electromagnetic radiations, and pseudophotographic agents, and a suitable developing procedure has been devised for the production of a sharply defined autoradiographic image of reproducible density. The emulsion exhibits marked fading of the latent image on delayed development and the latent image is completely destroyed by exposure to mercury vapor.

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[14] It has been found practical to study the nature of the streak produced on polished surfaces by transferring the powder from the scratch mark onto moist gelatin paper and examining the physical replica under oblique illumination. Preliminary experiments show that the minute streak exhibits the same characteristics as the macro streak on porcelain and individual grains can be tested microscopically by means of solvents and reagents. Details of this technique will be published shortly.

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TABLE 3. CLASSIFICATION OF THE URANIUM AND THORIUM MINERALS
(The more common species are indicated in bold faced type)

GROUP A: $P_\alpha = 338 - 224$

Uraninite: crystalline $UO_2 + UO_3$ and minor ThO_2.
Bröggerite: thorian uraninite.
Cleveite, Nivenite: yttrian and cerian uraninites.
Pitchblende: massive U_3O_8 with traces of ThO_2 and rare earth oxides.
Clarkeite: sodian gummite.
Becquerelite: $2UO_3 \cdot 3H_2O$.
Curite: $2PbO \cdot 5UO_3 \cdot 4H_2O$.
Schoepite: $4UO_3 \cdot 9H_2O$.
Ianthinite: $2UO_2 \cdot 7H_2O$.
Soddyite: $12UO_3 \cdot 5SiO_2 \cdot 14H_2O$.
Rutherfordine: $UO_2 \cdot CO_3$.
Sharpite (61): $6UO_3 \cdot 5CO_2 \cdot 8H_2O$.

GROUP B: $P_\alpha = 223 - 149$

Fourmarierite: $PbO \cdot 4UO_3 \cdot 5H_2O$.
Phosphuranylite: $3UO_3 \cdot P_2O_5 \cdot 6H_2O$.
Gummite: $UO_3 \cdot nH_2O$.
Vandenbrandite: $CuO \cdot UO_3 \cdot 2H_2O$.
Zippeite: $2UO_3 \cdot SO_3 \cdot 4H_2O$.

$\left.\begin{array}{l}\text{Voglianite}\\ \text{Uraconite}\\ \text{Medjidite}\\ \text{Uranopilite}^{15}\end{array}\right\}$ sulfates of uranium of uncertain composition.

Thorianite[16]: essentially ThO_2 with minor UO_2+UO_3.

$\left.\begin{array}{l}\text{Renardite}\\ \text{Dumontite}\\ \text{Dewindtite}\\ \text{Stasite}\end{array}\right\}$ lead uranyl phosphates of uncertain composition.

Trögerite: $3UO_3 \cdot As_2O_5 \cdot 12H_2O$.
Sklodowskite: $MgO \cdot 2UO_3 \cdot 2SiO_2 \cdot 6H_2O$.
Cuprosklodowskite (88): $CuO \cdot 2UO_3 \cdot 2SiO_2 \cdot 6H_2O$.
Uranosphaerite: $Bi_2O_3 \cdot 2UO_3 \cdot 3H_2O$.
Saléite (86): $MgO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$.
Pitchblende, dispersion of U_3O_8 in silica or clay.

GROUP C: $P_{\alpha}=148\text{–}100$

Uranocircite: $BaO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$.
Thorogummite: an alteration product of thorianite.
Nicolayite (82): similar to thorogummite.
Yttrogummite: an alteration product of cleveite.
Uranospinite: $CaO \cdot 2UO_3 \cdot As_2O_5 \cdot 8H_2O$.
Zeunerite: $CuO \cdot 2UO_3 \cdot As_2O_5 \cdot 8H_2O$.
Torbernite: $CuO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$.
Johannite: $(Cu,Fe,Na_2)O \cdot UO_3 \cdot SO_3 \cdot 4H_2O$.
Autunite: $CaO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$.
Bassetite[17]: $FeO \cdot 2UO_3 \cdot P_2O_5 \cdot nH_2O$.
Fritzscheite: $MnO \cdot 2UO_3 \cdot P_2O_5 \cdot nH_2O$.
Kasolite: $3PbO \cdot 3UO_3 \cdot 3SiO_2 \cdot 4H_2O$.
Uranophane: $CaO \cdot 2UO_3 \cdot 2SiO_2 \cdot 6H_2O$.
Carnotite: a hydrous vanadate of uranium and potassium.
Tyuyamunite: a hydrous vanadate of uranium and calcium.
Mackintoshite: a hydrous silicate of thorium and uranium.
Maitlandite (82): a variety of mackintoshite.
Brannerite: a hydrous titanate of uranium and rare earth oxides.
Crude Pitchblende: dispersions of U_3O_8 in siliceous rocks.

GROUP D: $P_{\alpha}=99-50$

Uranothorite: a hydrous silicate of thorium and uranium.
Orangite: a variety of uranothorite.
Enalite (43): a variety of uranothorite.
Auerlite: phosphorian thorite.
Hydrothorite: essentially $ThSiO_4 \cdot 4H_2O$.

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[15] Nováček (68) describes a bright yellow uranopilite, $6UO_3 \cdot SO_3 \cdot 16\text{–}17H_2O$ which changes on partial dehydration to a grayish-brown beta-uranopilite, $6UO_3 \cdot SO_3 \cdot 10H_2O$.

[16] Bespalov (7) describes a new variety of thorianite with 11.2–12.5 per cent lead.

[17] Bassetite originally described as a variety of autunite has since been shown by Meixner (60) to be a distinct species differentiated from autunite by its lack of fluorescence in ultraviolet light and the presence of iron in place of calcium.

Ferrothorite (48,83): ferrian thorite.
Calciothorite: calcian thorite.
Parsonite: a lead uranyl phosphate.
Uranothallite: $2CaO \cdot UO_2 \cdot 4CO_2 \cdot 10H_2O$.
Uranochalcite: a hydrous sulphate of uranium with variable amounts of copper and calcium.
Volgite: possibly a cuprian uranothallite.
Randite: a hydrous carbonate of calcium and uranium.
Uvanite: $2UO_3 \cdot 3V_2O_5 \cdot 15H_2O$.
Walpurgite: $5Bi_2O_3 \cdot 3UO_3 \cdot 2As_2O_5 \cdot 12H_2O$.
Betafite: a multiple oxide of uranium, columbium and tantalum.
Samiresite: plumbian betafite.
Blomstrandite: titanian betafite.
Mendeleyevite: calcian betafite
Ishikawaite: a multiple oxide of uranium, columbium, tantalum and rare earths.
Schroeckingerite[18]: $3CaCO_3 \cdot Na_2SO_4 \cdot UO_3 \cdot 10H_2O$.

GROUP E: $P_\alpha = 49 - 16$

Thorite: a thorium silicate, with uranium less than 2 per cent.
Eucrasite: cerian thorite.
Ellsworthite: uranian pyrochlore.
Hatchettolite: uranian pyrochlore.
Rauvite (76): $CaO \cdot 2UO_3 \cdot 6V_2O_5 \cdot 20H_2O$.
Ampangabeite: multiple oxide of columbium, rare earths and uranium.
Pisekite: possibly a variety of ampangabeite.
Freyalite: cerian thorite.
Djalmaite: possibly a tantalian variety of betafite.
Samarskite: a complex multiple oxide of uranium, rare earths, columbium and tantalum.
Nohlite: variety of samarskite.
Plumboniobite: plumbian samarskite.
Calciosamarskite: calcian samarskite.
Euxenite: a multiple oxide of columbium, titanium and rare earths.
Toddite: a variety of euxenite.
Polycrase: titanian member of euxenite–polycrase series.
Khlopinite: variety of euxenite–polycrase.
Fergusonite: essentially a multiple oxide of yttrian earths, columbium and tantalum.
Bragite: uranian fergusonite.
Vietinghofite: ferroan samarskite.
Delorenzite: a stanniferous multiple oxide of titanium, rare earths and uranium.
Thorotungstite (78): $2WO_3 \cdot 2H_2O + (ThO_2, Ce_2O_3, ZrO_2) \cdot H_2O$.

GROUP F: $P_\alpha = 16 - 5$

Cyrtolite, uranian (64): a hydrous silicate of zirconium.
Priorite, thorian: a multiple oxide of columbium, tantalum, yttrian earths and thorium.
Eschynite: a multiple oxide of columbium, tantalum, cerian earths and thorium.
Yttrialite: a silicate of yttrian earths and thorium.
Yttrocrasite: a multiple oxide of yttrian earths and titanium.

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[18] The mineral dakeite described by Larsen and Gonyer (50), has been shown to be identical with schroeckingerite by Nováček (69).

Caryocerite: a complex silicate of thorium and rare earth oxides.
Yttrotantalite: a multiple oxide of yttrian earths, columbium and tantalum.
Yttrocolumbite (52): probably identical with yttrotantalite.
Hjelmite: a stanniferous multiple oxide of rare earths, columbium and tantalum.
Monazite[19]**:** phosphate of cerian earths and thorium.
Tritomite: a rare earth fluo-boro-silicate.
Tanteuxenite: tantalian euxenite.
Naëgite: a variety of zircon containing columbium and rare earth oxides.
Zirkelite: a multiple oxide of zirconium, titanium and thorium.
Thucholite[20]: a thorian hydrocarbon.
Microlite: tantalian member of pyrochlore-microlite series.
Pyrochlore: columbian member of pyrochlore-microlite series.
Fergusonite: a multiple oxide of yttrian earths, columbium and tantalum.
Risörite: titanian fergusonite.
Sipylite: yttrian fergusonite.
Kochelite: an altered fergusonite.
Rutherfordite: an altered fergusonite.
Yamagutilite (42): variety of zircon containing rare earths, uranium and thorium.
Lyndochite: a thorian and calcian variety of euxenite-polycrase.
Steenstrupine: a hydrous thorian rare earth silicate.
Xenotime: phosphate of yttrian earths.

Group G: $P_\alpha = 4-0$

Microlite: varieties containing only traces or no uranium and thorium.
Eschwegite: probably a variety of euxenite.
Homilite (38): borosilicate of calcium and iron.
Erdmannite: a variety of homilite of uncertain composition.
Cyrtolite: an altered zircon with traces of uranium.
Corvusite: a hydrous oxide of vanadium with associated traces of uranium.
Priorite: a multiple oxide of yttrian earths, columbium and tantalum.
Wiikite: a multiple oxide of columbium, tantalum, titanium and rare earths.
Nuolaite: a thorian variety of wiikite.
Asphaltite (17): a uranian hydrocarbon.
Erikite: a silicophosphate of rare earths and aluminum.
Nagatelite (39): composition similar to erikite and possibly identical with it.
Melanocerite: a fluosilicate of rare earth oxides.
Allanite: a cerian epidote.
Polymignyte: a multiple oxide of zirconium, titanium, columbium and tantalum.
Zircon: $ZrO_2 \cdot SiO_2$.
Hagatalite (41): possibly a columbian-tantalian variety of zircon.
Oyamalite (41): variety of zircon.
Gadolinite: essentially $Be_2FeY_2Si_2O_{10}$
Calciogadolinite (65): a calcian gadolinite.
Rowlandite: a silicate of yttrian earths.

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[19] Most analyses of monazite show a range of 5 to 15 per cent of ThO_2. Higher concentrations are listed in the older literature (15), but these are likely to be erroneous in view of the difficulty of separating thorium from cerium. Gordon (31) has described a variety monazite from Llallagua, Bolivia, which is lacking in thorium.

[20] A titanian variety of thucholite has been described by Aminoff (1).

Hellandite: a rare earth silicate.
Johnstrupite: a rare earth silicate.
Mosandrite: a rare earth titano-silicate.
Cappelenite: a borosilicate of rare earths and barium.
Tscheffkinite: a rare earth titano-silicate.
Abukumalite (37): a silicophosphate of rare earths and calcium.
Kolm: a hydrocarbon containing traces of uranium.
Anthraxolite: a hydrocarbon containing traces of uranium.
Sphene: $CaTiSiO_5$.

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ACMITE OCCURRENCES ON THE CUYUNA RANGE, MINNESOTA

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Abstract

Acmite has been found in quantity in the rocks (taconites) and veins of the Cuyuna district, Minnesota. In other districts acmite is largely in igneous rocks and veins, but a diopsidic acmite was reported from Långban, in veins in hematite.

The analyses of Minnesota acmite show a high percentage of the "acmite molecule," $Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$; one of them purer than any other natural acmite that has been analyzed. This is a tea-green acmite in hypothermal veins. Disseminated acmite in the granules and matrix of the iron formation is brown. The brown color seems to be correlated with a manganese content rather than with other rare constituents.

A brown mineral has been known for a number of years in some high temperature veins in Cuyuna iron-bearing rocks and ores,[1] but it was variously identified by the writer and Doctor Thiel as epidote and pyroxene, for lack of good material. A recent exploration supplied a fair amount of drill core for a closer study. The drilling and study were financed by the University of Minnesota research funds of the Graduate School, and that support is gratefully acknowledged. The identification of acmite in this new occurrence is a minor incident to the main study of the stratigraphy of the Cuyuna rocks.

The drill core containing acmite is from a hole on the property of the Merritt Number Two Mine near Ironton, Minnesota. The collar of the hole is approximately 3100 feet north, and 4820 feet west of the southeast corner of Sec. 33, T. 47 N., R. 29 W. The hole was drilled diagonally down to the northwest almost at right angles to the bedding of the iron-bearing sediments. The acmite is abundant along the hole from a depth of 265 to 290 feet, showing that the acmite-bearing beds are 25 feet thick. The underground workings of the mine find the acmite very persistent along the strike of folded beds.

The beds adjoining the acmite rock show a series from the top down: (1) slaty, (2) cherty, (3) slaty; the terms used approximately as on the Mesabi Range,—slaty meaning very thin bedded, and cherty meaning somewhat variable wavy beds, one to 6 inches thick. The acmite is in and just below a cherty part of the series, which probably corresponds to the upper cherty beds of the Mesabi. In the Merritt mine it lies close below the beds of hard black manganiferous iron ore. Crosscuts from the ore into the footwall find very hard mining. Below the acmite rock are some hundreds of feet of softer carbonate slate and magnetite slate. The car-

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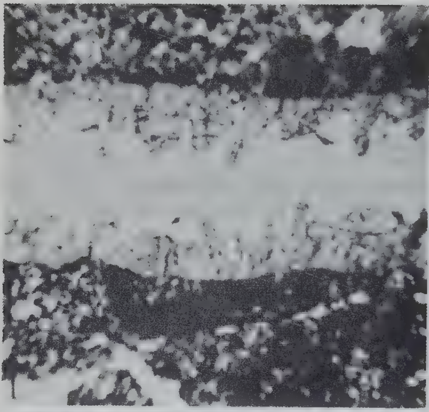
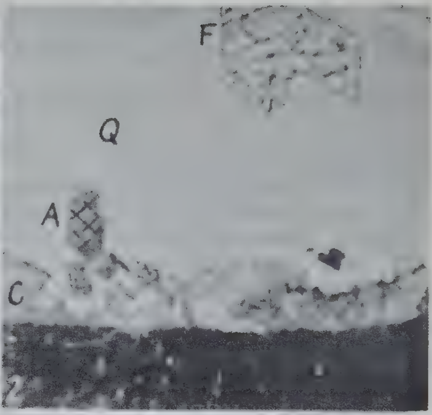
[1] Thiel, G. A., High temperature manganese veins of the Cuyuna range: *Econ. Geology,* **19,** 377–381 (1924).

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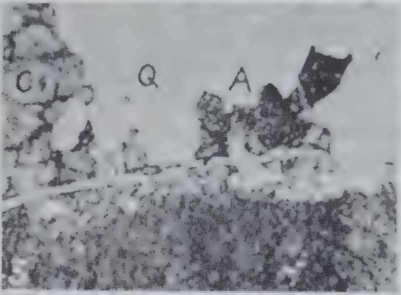
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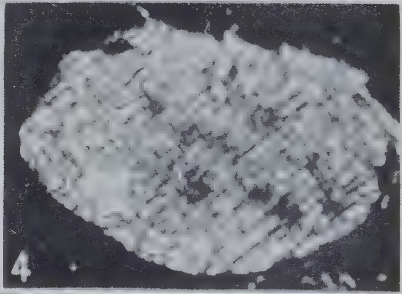
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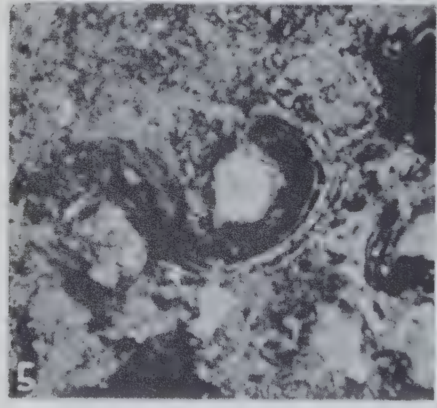
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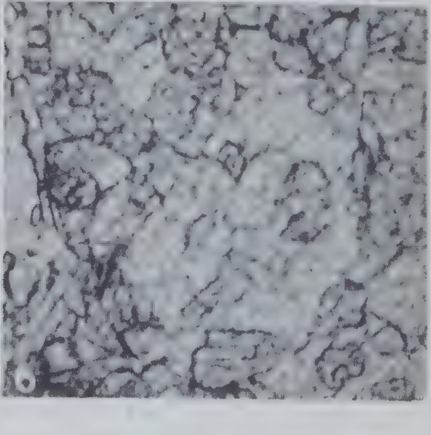
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bonate is largely manganosiderite in the slaty iron formation, and partly that in the veins, but some of the veins carry rhodochrosite, with minor amounts of calcium and magnesium.

The acmite is partly disseminated in the iron-bearing bed and partly in veins cutting the beds in considerable numbers. The veins carry rhodochrosite and were described by Thiel,[2] with the suggestion that at least part of the manganese of the Cuyuna ores is introduced. The same reasoning applies to acmite. It should be noted, however, that the acmite and rhodochrosite in veins seem especially abundant in those parts of the Cuyuna formation where the same minerals occur in the iron-bearing beds. Possibly there was some lateral secretion into the veins, or at least some reaction of vein solutions with the walls. The largest acmite concentration in a vein was $\frac{1}{8}$ to $\frac{1}{4}$ of an inch wide, and an inch or two long, alternating with quartz and pink carbonate irregularly.

Thin sections (Figs. 1, 2 and 3) show that the sequence of vein deposits is: (1) carbonate, (2) acmite, (3) quartz, and (4) adularia (valencianite of Winchell). In some veins one or more of the series may be missing. One slide shows enstatite and silicic plagioclase (as well as quartz and carbonate) associated with the acmite in a vein.

Thin sections also show acmite in the wall rock, partly as grains mixed with quartz and iron oxides (Figs. 3, 4 and 5), and partly as core and matrix of some oölites and "granules" like those of Mesabi taconite. The acmite grains show a wide range of dustiness from included hematite; some clear crystals, and some that are almost opaque.

The thin sections served to identify the acmite of these two occurrences, but since that in the vein is pale green and that in the rock is brown, it was thought best to test with x-rays. Doctor J. W. Gruner found both samples gave characteristic acmite patterns. The difference in color and the unusual occurrences led to optical tests (Table 1, columns 1 and 2). As Washington and Merwin noted,[3] "the pyroxenes are mark-

FIG. 1. Vein of acmite and quartz cutting taconite. (×32).

FIG. 2. The sequence from taconite wall is: (C) carbonate; (A) acmite; (Q) quartz, (F) adularia. (×32).

FIG. 3. Taconite wall rock and above it a vein. (C) carbonate; (A) acmite; (Q) quartz. A late quartz veinlet cuts the carbonate and acmite. (×32).

FIG. 4. An iron formation granule shows an acmite core with right angled cleavages. (×50).

FIG. 5. Oölitic structure involving hematite (black), acmite (gray), and quartz (white). (×27).

FIG. 6. Scattered subhedral acmite grains in a quartz matrix. (×66).

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[2] *Op. cit.*

[3] Washington, H. S., and Merwin, H. E., The acmitic pyroxenes: *Am. Mineral.*, **12**, 233–252 (1927).

edly zonal, so that, in most cases, optical methods or chemical analyses determine only approximate averages." The Cuyuna acmite shows some zoning, and the optical data are not reported beyond three significant figures. A comparison with data in the text books and recent papers suggested that these Cuyuna acmites had an unusually high content of the theoretical acmite molecule, and less of the usual diopside or other pyroxene molecules. Analyses were made to check this idea.

The brown acmite of the altered sediment was purified by crushing about 50 grams of core to 80 mesh, and dissolving carbonate by a brief treatment with dilute HCl; from the washed dried residue, quartz and other light minerals were mostly removed by floating them on bromoform. For the best sample, a core was selected where the acmite contained little hematite dust to start with; very little remained after acid treatment.

The green acmite, as it was picked out of the vein in fragments about $\frac{1}{8}$ inch thick, was more nearly pure. It was nevertheless given a similar purification. Microscopic examination of the 80-mesh concentrates showed quartz and hematite in very small amounts.

Analyses of Cuyuna acmites are numbers 1 and 2 of Table 1. Columns 3 to 8 of the table include the purest acmite analyses made or collected by Washington and Merwin[4] and one reported by Walker and Parsons.[5] Column 9 is added because of Washington's suggestion[6] that the brown color of some acmites may be from zirconia and ceria in the mineral. The compiled analyses suggest that the brown color is more likely a result of manganese. Column 10 gives the composition of the only pyroxene approaching acmite (about 3 parts acmite to 1 part diopside) that is said to occur in veins in hematite ore,[7] as does one of the Cuyuna samples.

A simple inspection of the analyses shows that the Cuyuna acmites are very rich in the "acmite molecule." Molecular proportions were calculated by the methods used and described by Washington and Merwin.[8] The green acmite of the vein has more than 91 per cent of the "molecule," higher than any of the other natural acmites. Other pyroxene molecules account for the remaining 9 per cent.

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[4] *Op. cit.*, pages 249–250.

[5] Walker, T. L., and Parsons, A. L., Acmite from nepheline syenite, French River, Ontario: *University of Toronto Studies*, No. **22,** page 12 (1926).

[6] Washington, H. S., The composition of rockallite: *Quart. Jour. Geol. Society*, **70,** 294 (1914).

[7] Sjogren, Hj., Urbanite, a new member of the pyroxene group: *Bull. Geol. Inst. Upsala*, **2,** 77–84 (1894).

[8] *Op. cit.*, pages 235–236.

TABLE 1. ANALYSES OF ACMITES FROM CUYUNA RANGE AND ELSEWHERE

	1 Cuyuna	2 Cuyuna	3 Quincy	4 Rockall	5 Ontario	6 Rundemyr	7 Greenland	8 Brevik	9 Libby	10 Urbanite	11 Theoretical
SiO_2	51.31	51.64	52.10	49.83	52.63	51.59	50.83	51.99	51.91	51.61	52.01
Al_2O_3	1.15	1.05	.99	none	3.30	2.06	1.76	1.32	.38	.74	
Fe_2O_3	32.08	32.98	31.80	30.27	29.72	28.65	28.70	28.16	21.79	27.24	34.57
FeO	.09	.14	.90	1.78	.64	2.08	3.07	2.18	1.48	.54	
MgO	.38	.38	.14	.27	.69	.35	.34	.44	3.08	2.75	
CaO	.59	.60	.57	1.65	.18	.30	1.30	1.59	5.53	4.90	
Na_2O	11.70	12.21	11.74	11.62	11.66	12.66	12.63	11.68	10.46	10.59	13.42
K_2O	.18	.06	.37	none	.54	.19	.36	.22	.22	.36	
H_2O+	.35	.41	.20	none	.26	.09	.10	.15	none	.90	
H_2O-	.01	.04							.06		
TiO_2	.06	.04	.60	.78	.35*	1.00	.23	.56	.91		
ZrO_2	none		.41	2.68		.20	.15	1.34			
S									.13		
MnO	.92	.26	.35	.28	trace	.14	.29	.10	.58	1.73	
V_2O_3	.04	.01							3.98		
rare earths	none		.48	.84		1.02	.11	.27			
	99.86	99.82	100.65	100.00	99.97	100.33	99.87	100.00	100.51	101.36	100.00
G	3.526	3.50±	3.587		3.487		3.509	3.591	3.55		
Est. Acmite H.S.W. method	88.30	91.49	89.17	86.39	86.85	82.70	82.70	81.31	62.83	80±	100.00
Color	Brown	Green	Grecn	(Both)	Green	Green	Green	Green	Brown	Brown	(Synthetic)
Gamma	1.81±2	1.80±2	1.823±2	1.81±1	1.801	1.825	1.824	1.810±5	1.782	—	1.836±4
Alpha	1.76±2	1.76±2	1.767±2	1.765	1.752	1.770	1.769	1.760±5	1.745	—	1.776±3
2V	80±10	80±10	60	—	63	—	—	—	80±	—	61
$X\wedge c$	6±1	6±1	6	4	—	3	4	0	2	—	8

* Ti_2O_3.

1. From taconite, iron formation, Cuyuna range, Minnesota. Lee C. Peck, analyst. Mean of two similar analyses.
2. From vein, with quartz and manganosiderite, cutting iron formation, Cuyuna range, Minnesota. Lee C. Peck, analyst.
3. From igneous rock, Quincy, Massachusetts. Mean of two similar analyses, by Warren and by Washington.
4. From igneous rock, from Rockall islet in North Atlantic. Composition calculated from rock analysis, by H. S. Washington.
5. From nepheline syenite, French River, Ontario. H. C. Rickaby, analyst.
6. Three centimeter zoned crystal from Rundemyr, Norway. H. S. Washington, analyst.
7. From igneous rock at Kangerdluarsuk, Greenland. H. S. Washington, analyst.
8. From Brevik, Norway. H. S. Washington, analyst.
9. From igneous rock, Libby, Montana. W. F. Hunt, analyst.
10. From Långban mines. R. Mauzelius, analyst. High summation probably resulted from the fact that some determinations were made on a different sample from others.
11. Theoretical composition of $Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$. Optical data for artificial acmite, by H. S. Washington.

The physical chemistry of acmite has been studied by Bowen and associates.[9] It is clear that hematite may be separated from crystals of acmite composition at temperatures above 850° C., as a consequence of incongruent melting. Possibly this relation may explain the common occurrence of dusty hematite in the acmite of most of the 25-foot bed in which Minnesota material occurs. The bed, however, shows no suggestion of igneous origin. It seems more likely that the Cuyuna acmite resulted from the action of hot sodic waters on hematitic cherts. Such a metamorphism may have occurred at temperatures below 850° C., and the hematite dust may be a residue of the hematite in the chert.

The optical characters of acmite have been well summarized by Washington and Merwin,[10] and the Cuyuna samples suggest no significant exceptions.

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[9] Bowen, N. L., and Schairer, J. F., The fusion relations of acmite: *Am. Jour. Sci.*, **18,** 365–374 (1929).

Bowen, N. L., Schairer, J. F., and Willems, H. W. V., The ternary system: Na_2SiO_3-Fe_2O_3-SiO_2: *Am. Jour. Sci.*, **20,** 405–455 (1930).

[10] *Op. cit.*

GEOLOGICAL MINERALOGY*

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One of my predecessors (Bayley) in his presidential address, referred to mineralogy as "mainly a laboratory science." That has been the traditional classification of mineralogy. The early mineralogist was also a chemist; he was a discoverer of elements, and inorganic chemistry can be considered to be a lusty offspring of mineralogy. Obviously, these pioneers in mineralogy were laboratory men. Both they and their successors have depended mainly upon collectors for specimens on which to work. For the record, the approximate locality where the collection was made has been ascertained. Further data concerning the occurrence have not been sought as a general rule.

During the past the mineralogist has been a bookkeeper, recording observations made with goniometer, balance, refractometer, and other measuring tools. Or he has been a chemist, analyzing and recording the composition of minerals. Or he has been a technologist, determining how minerals can be utilized in our so-called civilization. All of these are laboratory pursuits.

Where are we today? With the exception of mineral technology have not these laboratory phases of mineralogy reached and passed their zenith? Have not most of the angles, indices, and other properties of the known minerals been measured? Have not the minerals been analyzed? It is true that new instruments and methods have made possible more accurate results and so the older observations can be repeated. But is that all that mineralogy has to look forward to, rerunning older work so that results are accurate to the third instead of the second decimal place? I hope not.

Is it not time for mineralogy to venture forth from the laboratory and find out something of the origin of minerals through field studies? We have done a splendid job in assembling facts; let us now turn our thoughts toward interpretation. The natural history of mineral deposits is geological mineralogy, or paragenesis in the broadest sense of the word. The development of paragenesis as a field study was described by Palache in his address as retiring president of the Geological Society. Of all the branches of mineralogy it has been the most neglected.

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* Address of the retiring President of The Mineralogical Society of America, delivered at the twenty-sixth annual meeting of the Society, Pittsburgh, Pennsylvania, December 27, 1945.

Let us consider what is involved in geological mineralogy:

1. Field work. The geological mineralogist must map in detail and in three dimensions the mineral deposit under investigation. His studies should extend beyond the deposit contacts into the country rock. I feel very strongly regarding this latter point. Some years ago Newhouse invited me to contribute an article on the "Structure of Pegmatites" to his symposium on the structure of ore deposits. I then learned that there was very little published on the structure of the country rocks surrounding pegmatite intrusions. Furthermore, I learned, to my chagrin, that I was perhaps the worst offender in ignoring this important aspect of mineral deposition.

Concurrently while these studies are being made, the mineralogist is making an extensive specimen collection. And for his purpose, the most significant specimens are those containing a variety of minerals. A crystal in the hand is worth little compared to one in the matrix.

2. Laboratory work. This involves first the identification of every mineral, using all of the techniques of the laboratory mineralogist, and second, a careful study of the mutual relationships of the minerals in hand specimen, thin section, and polished section.

3. Cerebration. During this period the field and laboratory observations are assembled and studied, and a theory developed for the natural history of the mineral deposit which will be in accord with (*a*) the observations made, (*b*) the laws of physical chemistry,and (*c*) experimental work. This last point was stressed by Bowen in his presidential address in 1937.

4. Publication. With publication of findings the geological mineralogist has another opportunity to contrast his work with that of the conventional laboratory mineralogist. The publications of the latter, being in most cases at least entirely factual, are not subject to dispute. The conclusions of the geological mineralogist invite attack. Someone may duplicate the study and produce an entirely different theory. This leads to stimulating controversy. The only mineral deposit I have studied for which I am reasonably certain that my views on paragenesis will not be challenged during my lifetime is Barringer Hill, Texas. A power company very obligingly went in there after my studies were made and erected a dam which has caused the Barringer Hill pegmatite to become inundated under many feet of water.

Perhaps this account of the procedure followed in geological mineralogy has had a familiar ring. It is, of course, the procedure which has been followed by economic geologists of the "hard rock" type for many years. These geologists are also geological mineralogists, and some of their reports are classics in geological mineralogy. However, ore deposits are but one type of mineral deposit, and the other types also merit study.

The principal reason why the non-commercial mineral deposits have not been studied to any great extent is obvious. Neither a private mining company nor public institution is interested in paying salaries and expenses for such projects. However, I have never been refused a request for expense money from research foundations for studies of this type.

There is another handicap to geological mineralogy. That is the professional mineral collector. He has all the coyness of the old time prospector in divulging the location of the source of his specimens. For example, a number of papers written over 50 years ago describe some interesting minerals supplied by collectors, which came from "near Pike's Peak." A lot of country lies near Pike's Peak, and, on three sides of the peak at least, this country is extremely rugged. Consequently, the search for the source of the "Pike's Peak" specimens was difficult. I had better success in finding the Colorado cryolite deposit. It was described as, "from St. Peter's Dome," which is a mountain to the south of Pike's Peak. It took only five days of mountainside traversing to rediscover this vein.

One can appreciate the reason for reticence regarding the source of mineral specimens upon the part of an individual who is attempting to earn a living collecting. But when after making his collection, he discourages competition and prevents future study on the part of the geological mineralogist by setting off a blast which destroys access to the deposit, he is going much too far. To my surprise and regret I have also found museum curators, who are supposed to be men of science, guilty of such practices. It would not be so serious if the museum mineralogist took the proper notes and so collected his specimens that he, or someone else, could prepare later a paper on the paragenesis of the deposit. But, on the contrary the procedure of the usual curator, upon returning to headquarters, is to "clean" his specimens with cobbing hammer and dental tools until each is composed of a single mineral which has the purity of, and to the geological mineralogist about as much interest as, a bar of a well known brand of soap.

However, in spite of these handicaps, the opportunities in geological mineralogy were never greater than they are today. There are many here better qualified than I to tell of the opportunities which the economic geologists have, and have had during the war years, of working on the geological mineralogy of ore deposits. But the type of mineral deposit that has had the greatest relative development during the war years has been the pegmatite. No figures are available, but it is my humble guess that nearly as many pegmatites were opened up for exploitation during the war years as were developed in all previous historic time. I hope that someone better informed than I will tell us about the part played by the pegmatite minerals in World War II. One would gather, from the large number of geologists and mineralogists employed on pegmatite surveys by our government alone, that this role was an important one. The six papers on pegmatites listed on tomorrow afternoon's program are a result of these investigations. It is to be hoped that all who were assigned to pegmatites will prepare papers on the paragenesis of the deposits studied. But even if this should be done there will still be enough of these mineral deposits left to satisfy geological mineralogists for years to come.

But one does not have to work solely in ore deposits or igneous rocks in order to enjoy the pleasures of geological mineralogy. The sediments of both the present and the past contain many challenging problems. Tracing river and beach sands and gravels to bed rock source is a mineralogic and petrologic problem that has interested a number of investigators. The opportunities for further studies in this field are practically unlimited. Only a beginning has been made in using the mineral composition of drift materials to determine directions of ice movement.

Paleogeology, that relatively new field of study that promises to be so important in discovering the oil fields of the future, needs mineralogists to trace the grains in the sandstones back to their source. We in this country have not progressed as far in mineralogic studies of this type as the British had 40 years ago.

Last, but not least, among the opportunities for mineralogic work in sedimentary geology, are those presented by the chemical sediments. Since Van Tuyl's monograph on theories of dolomitization many of the great dolomite formations of the United States have been penetrated at innumerable points by wells drilled for oil, giving us a three dimensional picture of dolomite distribution not available before. New studies should be made of dolomitization, based on this evidence.

Likewise we now have excellent records, including well cores and cuttings, of many of the evaporite deposits in the United States. The experimental work of Usiglio on deposition of oceanic salts, now nearly 100 years old, does not have the applicability here that it has had at Stassfurt. The evaporites in the sedimentary basins of the United States present a magnificent opportunity for research in geological mineralogy.

Conclusion. Let there be more geological mineralogists! The only requirements, outside of educational background, are a prodigious curiosity, a vivid imagination, and a thick skin.

THIRD SYMPOSIUM ON DIAMONDS*

(1) INTRODUCTORY STATEMENT

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Ann Arbor, Michigan.

The exigencies of World War II greatly increased the demands for many minerals, and important new uses for some of them were developed. This is true of the diamond, especially of its use for industrial purposes. This expanded use of the diamond is of necessity based upon a fundamental knowledge of its crystallographic and structural properties. In this respect the diamond differs markedly from many other raw materials.

At the Boston meeting of the Mineralogical Society of America in December, 1941, the first symposium on diamonds was held. Eight persons participated in the program. The symposium was very well attended, and the discussion of the various papers was very gratifying, for much new information was given to those present. It was agreed that a second symposium should be arranged for the next annual meeting of the Society in 1942. Although no annual meetings have been held since 1941, papers for a second symposium were prepared. The papers of both symposiums were published in the March, 1942 and 1943, issues of *The American Mineralogist.* The demand for reprints in this country and from abroad has been unusually heavy. Since there has been no symposium since 1943, it was deemed highly desirable that papers discussing the present status and trends, as well as the new developments, some of which are truly remarkable, in the use of the diamond, should be prepared.

(2) DIAMOND PRODUCTION

SYDNEY H. BALL, *New York, New York.*

Now that the war is over, it may be said that the 2500-year-old diamond-mining industry under adverse conditions acquitted itself well in World War II. Staffs were depleted through enlistments, and supplies were none too abundant, but production not only held its own, but increased. The United Nations had enough industrial diamonds to speed up their machine grinding, to draw fine wire for their instruments, and to produce those perfect tolerances which permitted the interchange of similar parts of an aeroplane or other engine. The Axis Powers had too little. At one time, when Rommel and his tanks were rampaging through North

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* Conducted as part of the program of the annual meeting of the Mineralogical Society of America, Pittsburgh, Pennsylvania, December 27, 1945.

Africa, some of us had the jitters. Were the Germans to win the diamond fields of Africa, producers of 95 per cent of the world's rough, which for two years were almost in their grasp? Fate and Montgomery decreed otherwise.

Not a plane, a tank or a big gun was made during the war without the use of industrial diamonds. It needed a war to persuade the average citizen that the diamond industry had passed from a luxury to a luxury-utility trade. Sir David Brewster, writing in 1835, had realized it 110 years ago, when he said, "Had the diamond not been placed at the head of the mineral kingdom from its invincible lustre and high value as an ornamental gem, it would have attained the same distinction from its great utility in the arts."

The production of diamonds for the years 1942 to 1944 (down somewhat from the 1939 to 1940 average of, in round numbers, 13,400,000 carats) is shown in the following table, with a rough break-down as to gem and industrial grades.

	1942 *(Carats)*	1943 *(Carats)*	1944 *(Carats)*
World production	9,283,000	8,353,000	11,402,000
Gem stones	1,949,000	1,754,000	2,280,000
Industrials	7,334,000	6,599,000	9,122,000

It will be noted that the production of industrials varied a bit more over the period than that of gem stones. The 1944 production was equivalent to 5026 pounds avoir., of which 4021 pounds were industrials and 1005 pounds gem material. All of the production in 1942 was alluvial, 98 per cent in 1943, and 95 per cent in 1944. In 1942, 98 per cent of the African production stemmed from pre-Cambrian sources and two per cent from Cretaceous sources. In 1943 and 1944, the proportions were, respectively, 96 and four per cent and 91 and nine per cent.

The Belgian Congo, a producer of both gem and industrial grades—but particularly of the latter—was, as to weight, by far the largest producer. This was largely due to the BCK mine, which alone produces 60 to 66 per cent of the world's diamonds, by weight, although, because its product is almost wholly crushing bort, the percentage of values is but one-third that. As to diamond content, it is by far the richest diamond mine in the world. The war history of the Belgian Congo is interesting: First, many of the staffs joined the armed forces; later, gold and tin being considered by the colonial authorites more important commodities than diamonds, the staffs were further decreased and equipment and labor were shunted to the gold and tin mines. When in 1942 our War Production Board foresaw a possible shortage of crushing bort, supplies and new equipment were sent out to the diamond mines, and both staff and crew were reinforced.

The production of the Gold Coast and Angola remained stabilized during the war years. The production of Sierra Leone in the early years of the war was forced, lest the mines fall into the hands of the Germans. From 1942 to 1944, the production of the Union of South Africa trebled, largely due to the "green light" given to pipe mining in 1943. Dutoitspan and Bulfontein were reopened. Two or three years hence the Premier Mine will again be producing, and perhaps shortly thereafter the New Jagersfontein. In consequence, by 1948 we can expect a larger supply of fine cuttables and excellent industrials. South West Africa is increasing its rather insignificant production, and Tanganyika Territory since 1936 has had a remarkable rebirth as a producer. Brazil, Venezuela and British Guiana, notwithstanding the fact that during the war, and due to it, they received double the price accorded other producers, remained static and accounted for but four per cent or less of the world's production. Russia (the Urals) produced a few carats, and stones were found for the first time in Bolivia. The Japs, desperately but unsuccessfully, tried to increase notably the production of Borneo.

Industrial diamonds are in part a by-product of gem mining, the exceptions being the crushing bort produced by BCK in the Belgian Congo and the insignificant carbonado production in Bahia, Brazil.

During the period Sierra Leone joined the charmed circle of producers of large gem stones (older members, India, Borneo, South Africa and the Bagagem district in Brazil). In 1944 Tanganyika Territory produced a rather large gem stone.

The market for diamonds was broad and sales for 1943 and 1944 were unusually large. From 1941 to 1943 they almost trebled. The industry now has two products to sell, industrials (24 to 39 per cent by value, 80 per cent by weight) and gem stones. As the war progressed, the demand for gem stones increased, thanks to high war wages.

From 1940 to 1945, the price of industrial stones was stabilized; that of small cut trebled or quadrupled, and that of fine large cut doubled in price. But the "carriage" trade is a thing of the past and the retailer's bread and butter is now the medium priced diamond.

During the war, many a war emigre who was lucky enough to escape from the Axis fiends lived off his stock of diamonds, and perhaps had enough left to establish a small business in his newly adopted land. During the war diamonds have been a prime investment.

During the war an attempt, only partially successful, was made to differentiate clearly gem stones from industrials. While it is admitted that some rough is so flawless and crystal-clear that it would be a sacrilege not to cut it into gems and that other rough, lacking beauty, can be used only industrially, there is annually a large intermediate caratage which is used as gems or as industrials, according to whether the demand for the first or the second dominates.

The growth of the use of industrial diamonds has been phenomenal. In 1923 our country imported but three or four tens of thousands of carats, in 1933 but 300,000 carats, and ten years later 12,172,025 carats.

In 1923, $24 was paid for a carat, but in 1943, due to the increased use of crushing bort, but $1.81. In 1943 and 1944, the consumption of industrials was almost double their production.

Stocks of diamonds above ground decreased during the war period and "sands" and large rough, among the cuttables, and many grades of industrials became in short supply. Indeed, several types of industrials have been scarce for eight years. Industrial diamond toolmakers are advised to turn to "inferior" grades of industrials, provided they decide to remain in business. From a cost standpoint, such use will benefit both manufacturer and purchaser.

Up to 1941 production equalled or exceeded consumption; since then stocks have been reduced to the danger point. As to industrials, the diamonds in overalls, our government has a fair stock and our industrialists a little. The total is, however, not impressive.

At the beginning of the war, the United Nations controlled some 96 per cent of the world's production and toward the end, 99.99+ per cent. In consequence, the munitions industries of the United Nations never lacked for industrial diamonds. Germany, and especially Japan, however, were short of this essential strategic mineral. As evidence, we may cite Germany's desperate attempts to smuggle diamonds into her domains and the exorbitant prices she paid for industrials in Switzerland, and Japan's futile attempts to increase the production of the Borneo deposits.

During the war the sale and distribution of industrial diamonds was administered in Great Britain by the Diamond Controller and in the United States by the War Production Board. These controls are now being relaxed.

The future of the industry appears to be satisfactory. Stocks are small, indeed, non-existent as to certain grades. The industry is well co-ordinated. The demand for gems is large and that for industrials should be satisfactory, once industry is reconverted, although for some time it can scarcely equal wartime consumption.

Before I close, may I add that our country produces no diamonds; they are produced far from our shores. Industrial diamonds are essential to efficient munitions production. Diamonds are among those minerals which should be stockpiled in adequate quantities to safeguard our country's future.

(3) GEM DIAMONDS

LAZARE KAPLAN, *New York, New York.*

The diamond cutting industry in the United States is in a precarious position, as we predicted before this assembly four years ago. The manufacturers of small, or melee, diamonds are feeling the rising competition of Belgium, and to a lesser degree, Palestine, Holland, South Africa, Brazil, and other countries. All of these countries have a lower wage standard than the United States, and in some cases are receiving aid from their governments to enable them to resume their pre-war position in diamond cutting and polishing.

Besides, American manufacturers are short of rough material. The rapidly expanding European industry is taking a large share of the world's limited rough diamond stocks, and replenishing these stocks is difficult now, since many diamond mines were shut down because of the war. Some of these mines have deteriorated in the interim, and will require up to a year and a half before they can regain full production. This shortage of diamonds is just beginning to become critical, and may well become disastrous for many during the coming year.

After the cessation of hostilities, it was found that the diamond cutting industry in Belgium was in a better position than had been generally expected. In Antwerp particularly, diamond cutting was the first industry to begin working effectively, and at present there are between ten and fifteen thousand diamond cutters already working with equipment and tools which had been hidden from the Germans throughout the long occupation. Belgium has always been a very productive and industrious country, but unfortunately, in some instances those qualities have been coupled with too much ingenuity, and the result has been the organization of a black market both in diamonds and other commodities, on a staggering scale. To give an example of the rapid recovery of the diamond cutting industry of Belgium, their legitimate exports to the United States were $750,000 in September; $1,000,000 in October; and $1,200,000 in November. These figures exclude the very considerable black market trade, which apparently is mounting much faster than the legitimate trade.

The exports listed above are currently competitive with domestic production in small-sized diamonds, but are based on a lower cost—when the diamond boom is over and prices sag, Belgium has already proved her ability to undersell American diamond cutters producing similar articles.

Belgium, also is in a better position to obtain rough than the United States. First, her traditional position is very strong; for generations one of her main industries was diamond cutting, an industry of almost negligible importance in the United States. At present, Belgium has almost no other export trade, and depends entirely on the diamond industry for the livelihood of a considerable proportion of its people. Secondly, Belgium actually owns many of the world's richest diamond mines and dictates the policy that the largest share of the available rough shall go to Belgium. However, the Belgian cutting is not comparable to the better American makes, since their tradition to sacrifice some brilliancy in the diamond in order to get more polished diamonds from their rough is well-established, and also because their present-day clientele, anxious to purchase diamonds of any kind, cannot afford to be too critical.

Holland fared far worse during the occupation than did Belgium and is recovering far more slowly. By contrast with the Belgian diamond industry, the Dutch had the greater part of their machinery confiscated and their workers deported and have only 500 men working. Since many of the bridges crossing the numerous Dutch canals were destroyed, transportation within that tiny country is almost impossible. Where Belgium has thousands of diamond cutters working, Holland, with a pre-war industry somewhat comparable to Belgium's has only 500 diamond polishers at work.

The British diamond cutting industry is prosperous, but on a relatively smaller scale. Palestine has established a large industry, particularly in small-sized diamonds, but will shortly also feel the pinch of a shortage of rough material. South Africa has a relatively small, but well-established diamond cutting industry which will probably grow, due to its important proximity to the diamond mines and the fact that native manufacturers do not pay the 10 per cent export duty on rough diamonds. Brazil has well over a thousand diamond workers, who will certainly also be short of work unless their government adopts laws restricting the export of Brazilian rough diamonds to other countries. Cuba's thousand diamond workers are already dormant. Puerto Rico is continuing to manufacture on existing stocks, but being in a position exactly parallel to the American mainland industry, will shortly be curtailed or stopped for lack of raw material.

The world situation, therefore, is as follows: The Diamond Trading Company finds itself in a dilemma. Every country which had a diamond cutting industry before the war is clamoring for the return of that industry now. At the same time, those countries which developed industries during the war are striving for their continuation. As explained above, diamond mining was and is curtailed because of the war. The result is that there simply are not enough diamonds to fill all needs, even with the best of intentions on the part of the Trading Company.

It must be pointed out that one of the reasons why the Low Countries are struggling so anxiously for a large share of the world's diamond cutting industry is that it is a perfect export industry for them under today's conditions. The main market for polished stones is the United States, and every European nation is anxious to secure more dollars to help them with their reconstruction problems. The diamond industry provides very lucrative employment for the citizens of those countries. In view of the critical shipping shortage, the shipments of diamonds, tiny in physical bulk, can be made, easily and conveniently, by airmail.

As above suggested, diamonds are today eagerly sought in almost every part of the world, and for widely differing reasons. In the United States, the demand can be traced to the great number of marriages, to the shortage of other consumer commodities, and to the large amount of easy money in circulation. In our opinion, the American public is buying a relatively small amount of diamonds as a hedge against inflation, although this is certainly a secondary motive in many purchases. The rest of the world seems to be in sharp contrast on this point. Distrust of the currency and fear of inflation are widespread in other parts of the world and lead to the purchase of large stocks as hedges against any emergency. In England, the Low Countries, and France, for example, diamonds actually command prices higher than in the United States; and in the case of black market transactions, are sold for prices two or three times their American values.

(4) BONDED DIAMOND WHEEL APPLICATIONS

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Since the 1943 Symposium on Diamonds, the use of bonded diamond products in industry has shown consistent growth with more diversified applications. Improvements have also been effected in efficiency as related to the older applications.

Precision grinding of cemented carbide tools has been definitely established as a diamond-wheel application: first, because of the freer and faster cutting action of bonded diamond products and secondly, because of their ability to grind with imperceptible wheel wear, thus making it possible to readily maintain precision dimensional tolerances.

Where the work is applied manually, as in off-hand grinding, and where the application involves grinding steel and brazing metal, large wheels containing silicon carbide as the abrasive are still used for the roughing operation. However, there is also demand for diamond wheels in the smaller shops where equipment is limited, because of the longer life and smoother action afforded by diamond wheels; also, with metal-bonded products, it is often possible to use the same wheel for both rough and finish grinding, which is an advantage. In most cases the finishing operation is carried out with diamond wheels.

The development of vitrified-bonded diamond wheels, which was mentioned in the 1943 Symposium, has resulted in still further economies. This is due to a fast cutting action comparable to resinoid-bonded products, with at least double the durability. The vitrified wheels show a much greater ability to grind steel, and therefore, superior results have been obtained on cemented carbide applications where the percentage of steel to be ground is high.

The superiority of diamond wheels in the grinding of quartz, gem stones, glass, granite, marble and ceramic materials is being well established. All commercial quartz cutting in the United States today is done with diamond wheels. The cutting and grinding of synthetic sapphire boules is definitely a bonded diamond application.

The use of bonded diamond lens generators for the roughing operation in the manufacture of ophthalmic lenses is widespread. To the degree that precision equipment becomes available, it is expected that the preparation of these lenses will be simplified and will require diamond lens generators for the rough and fine grinding operations.

The precision grinding of various types of plate glass and glass prisms is now generally done with bonded diamond products.

Another promising field of application is marble and granite cutting, where data indicate better economy and much greater speeds of cutting than has been possible with such abrasives as silicon carbide.

It is interesting to note that the use of a proper lubricant is extremely important for grinding quartz, synthetic sapphire, and glass. A paraffin base oil gives a much freer and faster cutting action than soluble oil and water.

Of paramount importance in all diamond wheel applications is the condition of the grinding machine. Where excessive vibration is encountered short wheel life and resultant poor economy may be expected.

Improvements in control of raw materials, in bond compositions and in manufacturing processes are being actively sought, the objective being to improve economies and to develop products suitable in new fields of application.

(5) VECTOR HARDNESS IN DIAMOND TOOLS

Harry Whittaker, *Cranford, New Jersey*, and Chester B. Slawson, *University of Michigan, Ann Arbor, Michigan.*

Introduction

Early in 1942, shortly after the United States entered World War II, a possible shortage of industrial diamonds for dressing grinding wheels gave rise to an investigation of diamonds and their use for dressing grinding wheels. The investigation was sponsored by the Office of Production Research and Development of the War Production Board and was carried out in the Research and Development Laboratories of the Crane Company, Chicago, under the direction of the War Metallurgy Committee of the National Academy of Sciences. This paper, based on that work, has been released for publication by OPRD.

Although the research program was designed to determine the suitability of various grades of diamond under conditions that would be encountered in everyday industrial practice, the accumulated data yield upon examination some quantitative information in regard to the relative abrasion resistance offered by different directions within the diamond. These data have been assembled and are presented in this paper.

Abrasion Test Method

A variety of industrial diamonds was tested ranging from sound, first quality, clear octahedrons and dodecahedrons to the opaque coated stones typical of the Belgian Congo fields.

Description of Stones Yielding Vector Hardness Data

Specimen No.	*Description*
120	Grey white, clear octahedron
129	Brown, transparent rounded octahedron
141	Grey white, transparent dodecahedron
111	Yellow, transparent dodecahedron
43	Dark brown, translucent dodecahedron
136	Grey white, transparent octahedron-dodecahedron
139	Grey white, transparent octahedron-dodecahedron
184	Yellow, transparent rounded octahedron-dodecahedron
144	Belgian Congo, coated opaque octahedron-dodecahedron-cube
150	Belgian Congo, coated opaque octahedron-dodecahedron-cube
152	Belgian Congo, coated opaque octahedron-dodecahedron-cube
169	Belgian Congo, coated opaque octahedron-dodecahedron-cube
7	Belgian Congo, opaque cube
162	Belgian Congo, opaque cube

The comparison of the resistance of diamond to abrasion by grinding wheels presents a somewhat difficult problem since the diamond is exceedingly hard and wear on the diamond takes place at an extremely low rate. In order to measure the abrasion loss of diamond in a reasonable time interval, a test method was used which consisted of the continuous abrasion of the diamond with a grinding wheel and periodic measurements of the amounts worn off the diamond.

The essential parts of the test apparatus were a tool holder, so designed that any angular orientation could be given to the diamond, mounted on the table of a Brown and Sharpe No. 2 cylindrical grinding machine equipped with automatic feed, speed control, and traverse counter. Aluminum oxide grinding wheels twelve inches in diameter and one inch thick were used. Most of the tests were run on sixty mesh grit vitreous bonded grinding wheels, although some coarser wheels and some as fine as one hundred twenty grit were used, and some were resin bonded.

The diamond was mounted in a standard steel nib which in turn was mounted in the tool holder and oriented in the desired position. The tip of the diamond was then made to traverse across the face of the rapidly rotating grinding wheel removing 0.001″ from the face. After completing the traverse, the diamond was moved forward 0.001″ and then traversed back across the face of the wheel in the reverse direction. This process was automatically controlled and fifty passes across the face of the wheel constituted a test run.

Measurement of Abrasion Loss

The loss of weight in the diamond after such a series of dressings was so small that it could not be accurately weighed and so was computed from the volume removed. In order to determine the volume loss, the diamond, after being mounted in the nib and before the test run, was projected upon a screen with a 100× magnification, and a profile was drawn of the contour of the point of the diamond. After the completion of a test run, a second profile was made in the same position over the original profile. The outline of the facet or "flat" ground on the diamond was also traced under the same magnification and its area determined by tracing the outline with a planimeter.

The volume of the minute portion of the diamond removed was calculated as a pyramid whose height was given by the difference between the first and second profiles and whose base area was the area of the flat. The weight was computed using 3.52 as the specific gravity of the diamond. This method of computation assumes that the portion of diamond removed is a pyramid whose sides are flat surfaces. When, as is common in diamond crystals, the surfaces were curved or irregular, profiles of cross-sections at various positions were drawn and used in correcting the

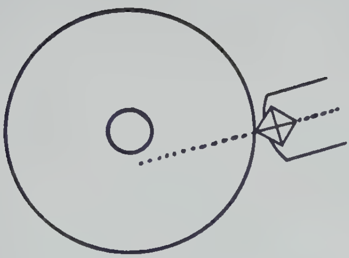

FIG. 1

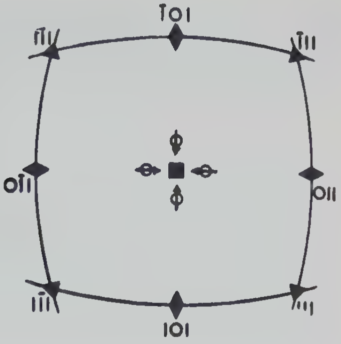

FIG. 2

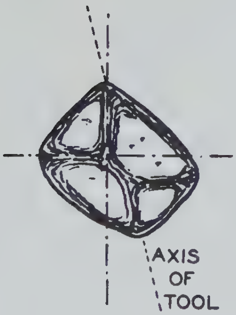

FIG. 3

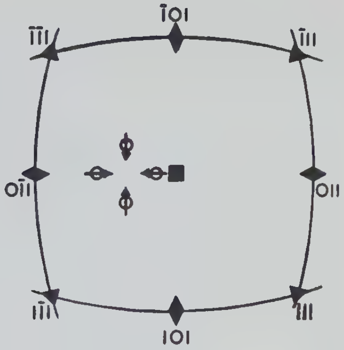

FIG. 4

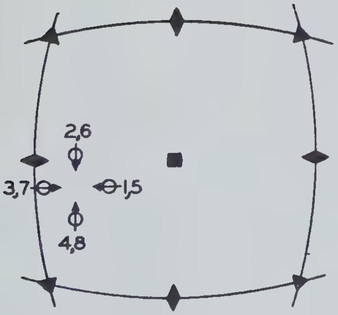

FIG. 5

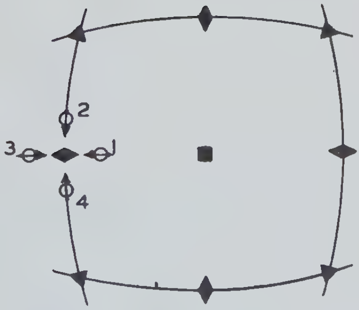

FIG. 6

volume determinations. An arbitrary *unit of wear rate* was established for comparative purposes by dividing the computed weight loss in carats by the volume in cubic inches of grinding wheel removed.

ORIENTATION OF ABRASION DIRECTIONS

Following the standard procedures used in industry the longest dimension of the diamond was mounted parallel to the axis of the tool. The tool was applied to the grinding wheel with the axis of the tool directed below the center of the wheel (Fig. 1). This is known in industry as giving a "drag" to the tool. The "drag angle" was 15°. After each test run the tool was rotated 90° about its axis. Thus after a complete rotation of the tool a series of four "flats" would be worn all equally inclined to the tool axis at an angle equal to the drag angle.

With a symmetrically developed crystal its longest dimension would be parallel to the crystal axis, and the series of flats would be equally disposed about (001). The position of these flats and the directions of abrasion across them is indicated in Fig. 2. With an unsymmetrical crystal the longest dimension is not parallel to a crystal axis (Fig. 3) and the series of flats are unsymmetrically disposed about (001), and if the deviation from parallelism (Fig. 4) exceeds the drag angle, (001) lies outside the circle of generated flats. In the first instance, the direction of abrasion is always towards (001), a hard vector direction of the diamond, but in the last instance there is one position during the complete rotation in which the abrasion direction is away from (001), a soft vector direction. In these projections the ground facets are symmetrically related to the diamond crystal. In general, the axis of the tool will not lie in a plane of symmetry, and the circle of generated flats will not be symmetrically disposed to any of the crystallographic elements. While checking the orientation of the diamond from the relationship of crystal faces and cleavages to the tool shank, it soon became evident that the soft abrasion direction took a high polish while the hard direction developed a fine matte finish. This observation made rapid preliminary orientations possible.

In Table 1, the data of twenty-two tests on fourteen stones have been assembled. The values for wear rate ranged from 2 to 100×10^{-5} carat per cubic inch of grinding wheel removed, which is the equivalent of one part by weight of diamond abraded to 200,000 to 10,000,000 parts by weight of grinding wheel consumed. In the abrading of these large quantities of grinding wheel in a test the diamond lost between 0.05 to 0.2 mm. in height and facets 0.2 to 1.0 mm.^{2} in area were ground on the diamond. A great diversity of test conditions is represented, but for each test the conditions are comparable, and the ratio of soft to hard directions remains consistently around two. The low values were those obtained on resin-bonded wheels, the high values on coarse grit vitreous bonded wheels which were run dry, i.e., without flooding the tool with water, which is the common industrial practice. The values do not represent a comparison of the hardest to the softest directions, but a comparison of the average of all hard directions encountered to the soft directions. The soft directions, as indicated in Fig. 4, are on surfaces nearly parallel to cube faces, the so-called four-point grain of the diamond cutters.

TABLE 1. COMPARISON OF WEAR RATES BETWEEN "HARD" AND "SOFT" DIRECTIONS IN DIAMOND

Specimen No.	Wear Rate (Dry) in Carat$\times 10^{-5}$/cu. in.		Ratio $\frac{\text{Soft Dir.}}{\text{Hard Dir.}}$
	Hard Direction	Soft Direction	
111	41	95	2.3
120	38	58	1.5
7	36	59	1.7
141	30	55	1.8
152	26	80	3.0
162	22	54	2.4
120	22	32	1.5
150	22	35	1.6
129	17	38	2.2
139	16	31	1.9
136	14	40	2.9
169	13	27	2.0
144	9	20	2.2
162	5	13	2.5
7	5	8	1.6
84	4.2	14	3.3
43	3.5	8.4	2.4
144	3.3	5.1	1.5
84	2.7	5.1	1.9
141	2.6	5.4	2.1
84	2.4	7	2.9
84	2.0	3.8	1.9

Table 2 presents the data on a series of test runs, all on the same tool, which was rotated ninety degrees between each test. The abraded point was the intersection of the octahedron, dodecahedron, and cube (Specimen No. 152). The position of the flats developed and the directions of abrasion across these flats are shown in projection in Fig. 5. In tests 2 and

6, the vector direction of abrasion is towards the dodecahedron, and the flat developed is nearly parallel to a crystallographic axis. This is the so-called two-point cutting direction of the diamond cutters and gives high wear rates. Tests 4 and 8 are likewise towards the dodecahedron face, but the facet makes a considerable angle with the crystallographic axis; hence while the wear rates are high, they are not as large as those obtained on tests 2 and 4. The other directions are hard directions.

TABLE 2. RELATIVE RATES OF WEAR RATE (DRY) OF DIFFERENT ORIENTATIONS OF DIAMOND

Test No.	1	2	3	4	5	6	7	8
Tool Rotation	0°	90°	180°	270°	0°	90°	180°	270°
Wear Rate $\times 10^{-5}$ ct./in.^{3}	18	68	22	27	40	94	25	47

In shaping the wheel for grinding threads, a very sharp point of a diamond is needed, because of the close tolerances to which these threads are held. Diamonds used for this purpose are known as thread dressers. Natural octahedrons with sharp points or lapped points with the apex at the end of a crystallographic axis are most suitable. When points are lapped on the ends of cleavage splinters, the wear rate on the diamond point was found to be as much as three times as great. These results were to be expected, because cleavage splinters are elongated parallel to a binary axis of symmetry. The binary axis of symmetry is normal to the dodecahedron face and the abrasion conditions are shown in projection in Fig. 6. The diamond abrades very rapidly along the direction of the so-called two-point cutting grain of the diamond cutters, 2 and 4, the softest direction on the surface of the diamond. The directions 1 and 3 are hard.

CONCLUSIONS

1. No significant differences in abrasion rates were revealed which can be attributed to color, transparency, size, shape, or geographical origin.
2. Those directions which are crystallographically weaker directions show higher losses due to abrasion.
3. Facets abraded along the softer directions acquire a high polish.
4. The preference shown in industry for well-formed octahedrons can be attributed to the fact that when the conventional methods of mounting and using the stones are followed, there is little likelihood that the softer directions will be presented to the wheel when dressing grinding

wheels. Distorted and ill-shaped stones will give equally good results if mounted with a crystallographic axis parallel to the axis of the tool.

(6) OBSERVATIONS ON ORIENTATION AND HARDNESS VARIATIONS

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As described by Whittaker and Slawson,[1] hardness is a vector property that varies considerably in diamond crystals. It is my purpose to describe some results obtained in the laboratories of the Hamilton Watch Company, indicating a probable ratio of 100 to 1 for the hardnesses of the hardest direction in the hardest surface and of the softest direction in the softest surface. These experiments were conducted under conditions of unidirectional rubbing of a flat diamond surface against stainless steel watch parts. A polished, flat diamond is used to burnish the watch parts by rubbing the two together under considerable pressure, and with no vibration. This condition of high pressure, vibrationless rubbing between diamond and metal would represent approximately the conditions of service that must obtain in wire dies, except for the complications due to the curved surfaces of the dies. It is probably not representative of the conditions of use encountered by diamond wheel-dressers, where at least some vibration and shock seem almost certain, and where the tendency of a pointed tool to fracture easily probably masks some parts of the range of hardnesses.

Kraus and Slawson[2] described the general pattern of hardness variations; their qualitative results now need to be augmented by quantitative studies. The beginning of such a program was undertaken by the Hamilton Watch Company in a successful effort to lengthen the life of certain diamond tools used in the factory.

The production that can be expected from a tool in which the softest direction of the softest surface is presented against the stainless steel parts, is less than 200 units; but the same tool, made with equivalent quality of diamond, but so oriented as to present the hardest direction of nearly the hardest surface, will consistently produce 20,000 such units; in one case characterized by unusually skillful handling by the machine operator, over 100,000 units of production was achieved. The stated ratio of 100 to 1 for the maximum range of hardnesses is therefore probably not too high.

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[1] Preceding paper.

[2] Kraus, E. H., and Slawson, C. B., Variation of hardness in the diamond *Am. Mineral.*, **24,** 661–676 (1939).

Kraus, E. H., and Slawson, C. B., Cutting of diamonds for industrial purposes: *Am. Mineral.*, **26,** 153–160 (1941).

It is essential to be able to specify and measure the orientation of any direction in any surface of a diamond crystal. Perhaps I may compare the crystal with a sphere such as the earth. Crystallographers recognize a north pole in the diamond sphere just as geographers recognize one on the earth. Likewise there is a prime meridian on the diamond sphere, just as there is a prime meridian through Greenwich, England, on the earth. Crystallographers have long used these coordinates of longitude and latitude to locate points on spherical projections of crystals. Now let us suppose that our diamond sphere is touching a flat lap. The point of contact can be specified in terms of the coordinates of longitude and latitude just described. Moreover, just as a ship on the high seas steers along some course selected by the captain, so the surface of the lap is abrading the diamond sphere at the point of contact, in a certain direction called the azimuth of abrasion. Thus crystallographic longitude and latitude may be used to specify the orientation of a plane surface—artificial or natural—and crystallographic azimuth may be used to specify a direction in that surface. The measurement of these coordinates in a crystal may be likened to the fixing of a location at sea by astronomical observations. But navigation in crystallography is another subject and must be considered elsewhere.[3]

Observations of hardness or wear resistance have been collected for several years in the Hamilton laboratories. Hardness is expressed in terms of the number of similar units of production obtained by identically shaped, but differently oriented diamond tools. Each diamond was selected in the laboratory, and assigned its orientation. It was then polished on a mechanical fixture so as to obtain the best possible uniformity of shape and size. The polish and exact crystallographic orientation were then examined in the laboratory before forwarding the tool to the production department where it was used. When a tool ceased to be productive for any reason, it was returned to the laboratory. The reasons for failure generally belong to one of three groups: (1) the diamond surface is worn out; (2) the diamond was improperly set; (3) accidental damage occurred. Results that I am about to describe were obtained from diamonds that were rejected for the first reason—worn surface.

Figure 1 is a photomicrograph showing an extreme case of this condition. The diamond surface, as originally polished, would be perfectly smooth and featureless; after rejection for a worn surface, there are usually some fine lines or grooves across it in the direction of the motion of the work pieces. This photomicrograph shows more than the usual number of such lines, running from top to bottom. The diagonal lines are structural features of the diamond crystal, and would not be found on most crystals. As stated, this particular one was exceptionally badly worn. Most tests were concluded when the tool had light grooves that were deep enough to spoil the mirror finish desired on the metal work pieces, but not conspicuous enough to show clearly in a photomicrograph. The number of work pieces successfully produced by a tool is taken as the hardness of the diamond surface in the direction concerned.

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[3] Winchell, H., Navigation in crystallography: *Geol. Soc. Am. Bull.*, (in press).

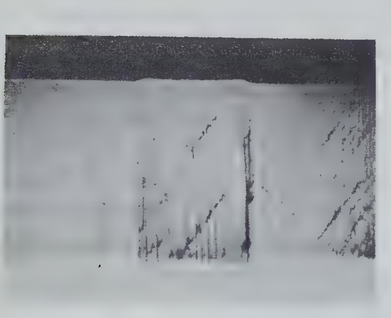

FIG. 1. Surface of diamond tool after exceptionally heavy groove had been worn across burnishing facet. Facet is 0.010″ wide from top to bottom.

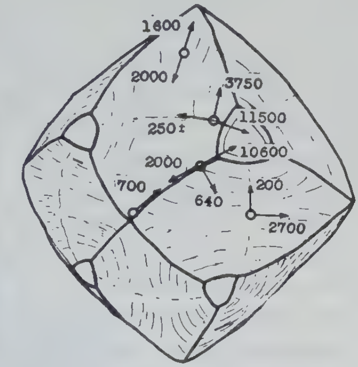

FIG. 2. Sketch of a rounded dodecahedral diamond crystal, schematically showing the approximate average relative resistance to abrasion in several directions at points indicated by circles.

The actual values of the hardness readings so obtained range from less than 200 to well over 20,000, depending upon the orientations of the diamond tools. In order to represent most of the observations on a simple diagram, I have grouped together all observations in certain ranges of orientation, and Fig. 2 shows the averaged results for these groupings. Note that the maximum range of hardness values shown is less than 100 to 1 because the highest hardnesses have been averaged with hardnesses obtained from other nearby orientations that were not so hard.

Surfaces crystallographically equivalent to various trisoctahedrons (*hhl*) and fairly close to the octahedron (111) were averaged together. Most of the observations on such surfaces were made in the direction toward the octahedron: their average is 11500. The opposite direction is indicated as approximately 250. This is probably a maximum hardness rather than a valid determination of the average, since considerably more wear is usually visible after producing these 250 pieces than after producing 20,000 in the hard direction. A third direction in surfaces of this type gave an intermediate hardness value, 3750.

Surfaces crystallographically equivalent to various trapezohedrons (*hll*) and also fairly close to the octahedron, were tested in several directions enough times to indicate appreciable variations in the hardness. Such surfaces, abraded toward the octahedron, yielded an average of 10,600 pieces before wearing out. The same surfaces abraded in the opposite direction gave only 2000 pieces. And if abraded at right angles to that direction, much trouble was encountered in setting up the tools, and the average production was only 640 pieces. It is not certain that this or the 2000 observation is a valid determination of the relative hardness.

Surfaces approximately parallel to the dodecahedron (110) gave widely varying hardnesses, depending as expected upon the direction of abrasion in the surfaces. Parallel to a crystallographic axis, in the "polishing grain" of the surface, the production averaged 200 units, although this is probably high, since much deeper grooves were generally worn in the surface while making this test than were produced in differently oriented surfaces or in other directions in this surface. This is probably the softest surface and direction of all. The hardness measured at right angles to this direction was about 2700, or more than 10 times as great.

Surfaces in the tetrahexahedral zones (*hk*0) and surfaces nearly parallel to the cube face (100) were not tested thoroughly. A few observations gave the results shown in the figure, but these are of a lower order of accuracy than the trisoctahedron, dodecahedron and trapezohedron tests.

In general, it is emphasized that these are all preliminary data, possibly subject to wide errors, even though their orders of magnitude are probably about right. The quality of polish on each of the surfaces tested was good, and as uniform as could be obtained, but the best polish was obtained on surfaces in the zone including the dodecahedron and the various trisoctahedrons. Octahedral faces themselves are practically impossible to polish. A few tests on a surface nearly parallel to an octahedron indicated the importance of a superior polish in the work, and pointed a warning that this factor must be carefully controlled.

CONCLUSION

Preliminary work on a diamond tool used for burnishing stainless steel watch parts has shown that crystallographic orientation largely controls the rate of wear, and therefore the ability of the tool to produce a large quantity of satisfactory work pieces. The best orientation for this type of tool utilizes the remarkably large variation of hardness of trisoctahedral surfaces to provide a very high hardness in the direction used for burnishing, and at the same time, a very easy "polishing grain" in the opposite direction. These results are sufficient for technological purposes, but only preliminary for purposes of accurate study of the variations of hardness.

(7) THE PREPARATION AND STANDARDIZATION OF DIAMOND POWDERS

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INTRODUCTION

The investigations sponsored by the War Production Board on diamonds for use in the manufacture of war materials, such as wire-drawing dies, cutting tools and instrument bearings soon disclosed a need for the investigation of the diamond powder which was used in preparing the diamond articles. For example, diamond dies for wire drawing often showed detrimental grooves in the drawing cone (Fig. 1) which apparently were caused by the presence of over-size diamond particles in the dust used for drilling. Conversely, the presence of excessive amounts of very fine material often caused inefficient action.

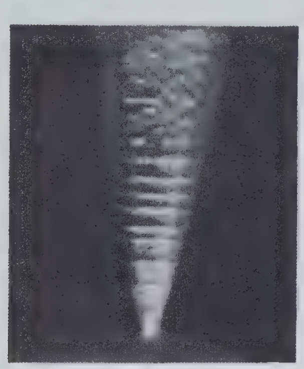

FIG. 1. Photomicrograph of the drawing cone of a diamond die for wire drawing showing grooves in the primary cone caused by oversize grains of diamond dust used in drilling. Magnification, 94×.

A microscopic examination of the diamond powders obtained commercially showed that (1) the classification of diamond powders for size was almost without exception poor, (2) diamond powders were in a few cases contaminated with lint, grease and inorganic impurities, and (3) the designation of size grades was non-uniform and without relation to the actual particle size.

In view of these conditions the War Production Board authorized the National Bureau of Standards, under the sponsorship of the War Metallurgy Committee, to undertake an investigation of diamond powders with the principal objects of (1) determining the efficiency of various methods of grading powders for size, (2) selecting a method of size fractionating which would be useful under commercial conditions, and (3) assisting in devising a standard of uniformity of fractionated powders which would be useful and commercially feasible. This paper is a condensed account of the methods used and the results achieved. A detailed description will appear in the Journal of Research of the National Bureau of Standards in the near future.

Methods and Results

As an essential first step in size fractionation or in determining particle size, it is necessary to find a medium in which diamond powder will disperse. A liquid medium to be effective must wet diamond and must develop an electric charge on diamond particles when the diamond and liquid are in contact. Other properties of the liquid such as viscosity and specific gravity are also of importance. Wettability was determined simply by observing whether a liquid, brought into contact with clean diamond particles, surrounded the particles or pushed them away. The development of an electrical charge was ascertained by observation under the microscope of the migration of diamond particles immersed in a liquid in a simple electrophoresis cell.

It was found that in all the liquids tried the diamond particles developed a negative charge. The liquids were judged on the basis of their dispersive power, i.e., on the basis of the absence of aggregates and the Brownian movement of fine particles, and were given a rating of excellent, good, fair, or poor. For the purpose of size fractionation, only two of the more than 30 liquids examined were given a grade of excellent. One of these was the general group of pine oils in various viscosity grades and the other was a 1/10 to $\frac{1}{4}$ per cent solution of gelatin in H_2O to which enough sodium carbonate had been added to give a *p*H of about 9. Ethylene glycol, glycol sebacate, hexaldehyde, oleic acid, olive oil and a $\frac{1}{5}$ per cent solution of calcium lignin sulfonate in water were found to be good dispersants although two were too viscous and one was too expensive to be practical for use in settling or elutriation procedures. It is interesting to note that ethyl alcohol, which apparently has been widely used commercially, was one of the poorest dispersants tried. Microscopic observation of diamond dusts fractionated commercially in alcohol almost invariably showed poor size grading.

In photomicrography, excellent mounts of well dispersed diamond powder are obtained by stirring the powder well into Canada balsam melted on the object slide. Hyrax also gives good mounts.

Separation Methods

The selection of a method of separation for commercial use is based principally upon the following considerations: (1) a quality of size fractionation which will meet the demands of the user, and (2) an economy in cost and operation of the machine which will make the apparatus commercially feasible.

The methods of separation considered fall into three general classes:* centrifuge methods, gravity settling and elutriation. The discontinuous centrifuge method when operated according to the specifications of the Research Laboratories of the British General Electric Company was known to give a product of excellent quality, but due to the amount of attention required by an operator for the amount of dust separated and to the expense of equipment and supplies, it did not appear suitable for commercial use.

Direct gravity settling gives good results when proper precautions are taken as to temperature uniformity, proper settling medium, proper methods of removing fractions, and requisite number of repetitions of the settling process, but the method is very time-consuming.

A modified form of the Cooke elutriator was finally selected as embodying features most useful in fractionating the diamond powders commercially. This instrument is described and illustrated in Report of Investigation #3333, *United States Bureau of Mines.* The modifications introduced in the diamond powder investigations, such as changes in the reservoir for maintaining constant head, will be fully described in the final report. For a dispersing medium, a 1/10 per cent solution of gelatin was used to which was added sufficient sodium carbonate to give a *p*H of about 9 and sufficient thymol to prevent bacterial growth.

In operation, a slurry of diamond powder and gelatin solution is placed in a can into which the gelatin solution flows at constant rate under constant head, adequate precautions being taken to prevent turbulent flow through the diamond suspension. The rate of upward flow through the diamond suspension determines the size of grain washed over the edge of the can. Assuming constant and non-turbulent flow with adeuqate stirring of the diamond dust in the can, all the diamond grains of one size can be separated provided sufficient time is allowed. The finer particle sizes are separated first by beginning with the slower flow rates.

The results were quite satisfactory and well within the tolerances of the commercial standard as finally proposed and adopted. Provided large enough reservoirs for liquid and for separated powder suspensions are furnished, the machine will operate with very little attention.

The liquid elutriation method has the advantage over the gravity settling method that the former can theoretically separate completely in one operation all the grains within definite size limits whereas the gravity method can only approach asymptotically a complete separation with repeated mixings and settlings. The liquid elutriation method, moreover, requires the lesser attention of an operator for an adequate separation of sizes.

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* This study was largely confined to sub-sieve sizes since the powders in the range of commercial sieve sizes were in general found to be well graded.

Commercial Standard

A Commercial Standard (CS123-45) drawn up by the National Bureau of Standards and put into operation on May 5, 1945, provides a basis for agreement beteeen purchaser and seller on uniform size and purity grades of diamond dust. It is principally valuable in that (1) it furnishes a designation for size grades of diamond dust based on the average particle size in microns, and (2) it provides size grades of dust with minimum and maximum limits which are adequate for the user and attainable by the producer. Seventeen size grades are provided beginning with 1 (minimum size 0, maximum size 2 microns), proceeding up the scale with graduated increase in size and in tolerance and ending with 400 (minimum size 250, maximum size 550 microns). This standard has already reduced the confusion in the buyer's mind caused by arbitrarily selected designations of powder sizes which had no relation to actual sizes in any mensural system.

(8) APPLICATION OF THE HIGH VOLTAGE ARC TO THE CUTTING, SAWING, AND DRILLING OF DIAMONDS

Chauncey G. Peters, *National Bureau of Standards, Washington, D. C.*

While the larger wire dies of both diamond and carboloy have been produced domestically for a number of years, all the small diamond dies of .002″ to .0004″ in diameter were imported from Europe. When the war completely cut off this supply and at the same time enormously increased the requirements for fine wire, the War Prodcution Board took active steps to encourage and assist domestic plants in the production of these critical dies. A report on the progress of this program is given in an article "Diamond Dies," Alexander Shayne, *American Mineralogist*, **28**, 145, 148 (1943). In spite of this effort it was found by January 1943 that the number and quality of the dies produced were below requirements and the assistance of the National Bureau of Standards was requested. Under Project NRC-535 a die laboratory was instituted at the Bureau with the purpose of reducing production time and cost, and improving the quality of dies.

Machines of the type in general use were installed and operated but it soon became apparent that no appreciable reduction in drilling time could be made over the average experience of the industry.

Fortunately, at that time, with the aid of apparatus previously used in the Interferometry Laboratory for depositing metallic films, holes about .020″ deep and .004″ in diameter were drilled in diamonds in about 15 minutes time. The arrangement of this high voltage apparatus as now being used is shown in Fig. 1. The leads from the 110 V, 60 cycle a.c. outlet are connected to the primary of a 0 to 120 V output variac, *V*. The secondary of the variac is connected to the primary terminals of a 10,000 volt, 300 VA power transformer, *T*. In one of the primary connecting leads a variable rheostat, *P*, of 200 ohms (not shown in the figure) is placed and in the other an alternating current ammeter, *A*, of 2 ampere range. A capacitor, *C*, of about .0004 microfarad is connected across the secondary leads of the transformer. Control and speed of drilling is improved by inserting a quenched spark gap, *G*, in one secondary lead of the transformer.

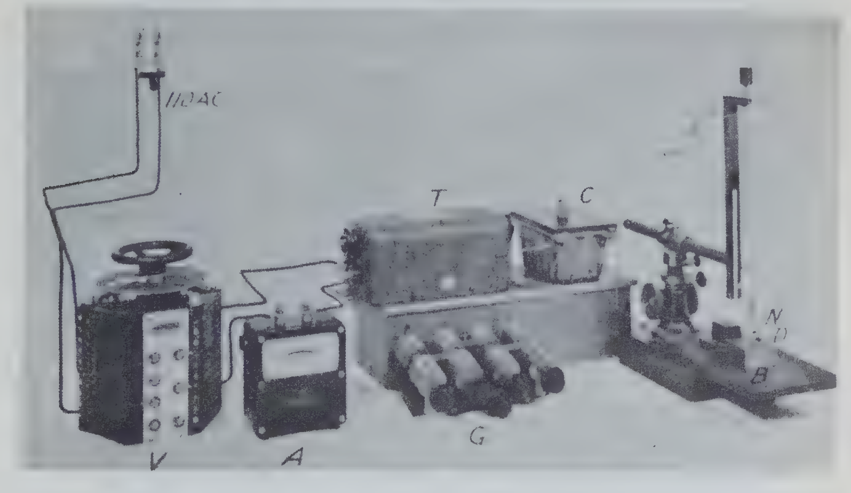

Fig. 1. Apparatus for high voltage, electrical fore-drilling.

One of the secondary leads of the transformer is connected to the brass base block, *B*, which supports the diamond, *D*, and the other lead is connected to the drilling needle, *N*, which is made of 0.020″ diameter, 70 per cent platinum-30 per cent iridium wire and contacts the diamond.

Adjusting the current to about one ampere by means of the variac, a white arc extends from the needle to the brass pillar and a hole of about .020″ depth shown in Fig. 2, is drilled in 8 to 10 minutes. The die is then transferred to a light drilling machine and the primary cone shown in Fig. 3, is reamed. (This operation requires about 45 minutes time.) The cone angle is controlled by the shape of the needle. By repeating the two operations a primary cone of about .040″ depth is produced.

The previous method of making dies has been essentially a star drilling operation, that is, the diamond is tapped rapidly by a sharp pointed needle covered with diamond powder. This action causes the point of the steel needle to almost immediately break down with but little effect on the diamond. For this reason, from 75 to 150 hours were required to drill through a die blank of .050″ thickness.

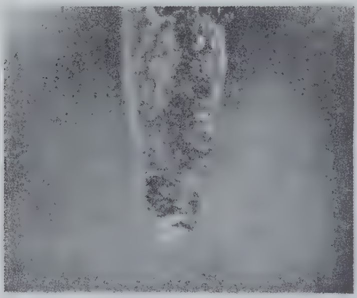

Fig. 2. Fore-drilled pilot hole. ×73.

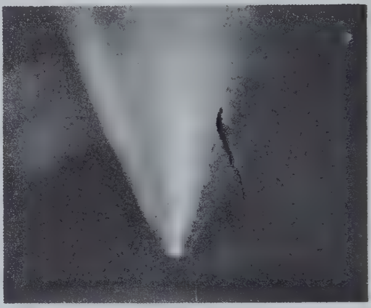

Fig. 3. Countersunk bell cone. ×73.

With the method here described the hole is fore drilled by means of the electric arc. The point of the drilling needle follows this pilot hole without coming in contact with the diamond and the rapidly rotating side of the needle cone charged with diamond powder, laps, or reams the primary cone to desired form.

The drilling and polishing of the secondary cone and bearing is discussed in the second part of this report. (See following paper.)

Applying the high voltage arc to the lapping machines used for cutting flat facets on diamond, the cutting rate is materially increased for all orientations of the diamond and good progress can be made directly on a natural octahedron face, where cutting without the arc is almost impossible. The arrangement of the apparatus is shown in Fig. 4 which is the same as for Fig. 1 except that variac and quenched spark gap can be dispersed with.

One secondary lead of the transformer is connected to the dop, *F*, which, holds the diamond, *D*, and is supported by the insulating arm, *B*. The other lead is connected by the brush, *E*, to the lap, *L*. When a current of about 0.5 ampere is applied a small arc appears at the contact of the diamond and lap. A description of the apparatus and a table of the cutting rates for different orientations is given in the *Journal of Research* of the National Bureau of Standards, Vol. **34,** p. 587, June, 1945. Reprints can be obtained from the Bureau or the Government Printing Office, Washington D. C.

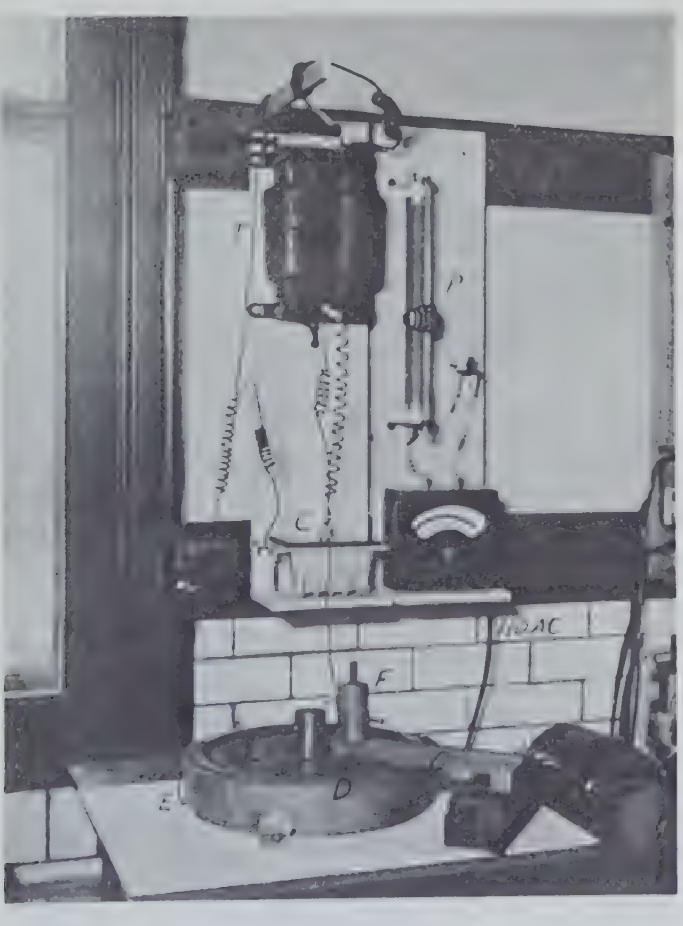

Fig. 4. Diamond lap with electric equipment and connections.

The electric arc has also been applied to the diamond saw. With the same arrangement shown above one lead is connected to the insulated dop, while the other lead is connected to the saw by means of a light phosphor-bronze brush. From published accounts, sawing could only be performed in certain directions parallel to either a cube or dodecahedron face. With the arc however, relatively rapid sawing can be done regard-less of the cutting direction. Saw cuts have been made with the periphery of the saw traveling parallel to the octahedron face.

(9) CONTROLLED ELECTROLYTIC DRILLING OF DIAMOND

Walter B. Emerson, *National Bureau of Standards, Washington, D. C.*

The purpose of project NRC-535 undertaken by the National Bureau of Standards in January, 1943, was to improve production of diamond wire-drawing dies .0004″ to .0015″ in diameter. It soon became apparent that any appreciable decrease in production time would have to come from improved methods for drilling the secondary cone. This operation required from 75 to 125 hours for dies .001″ or less in diameter when performed on existing machines.

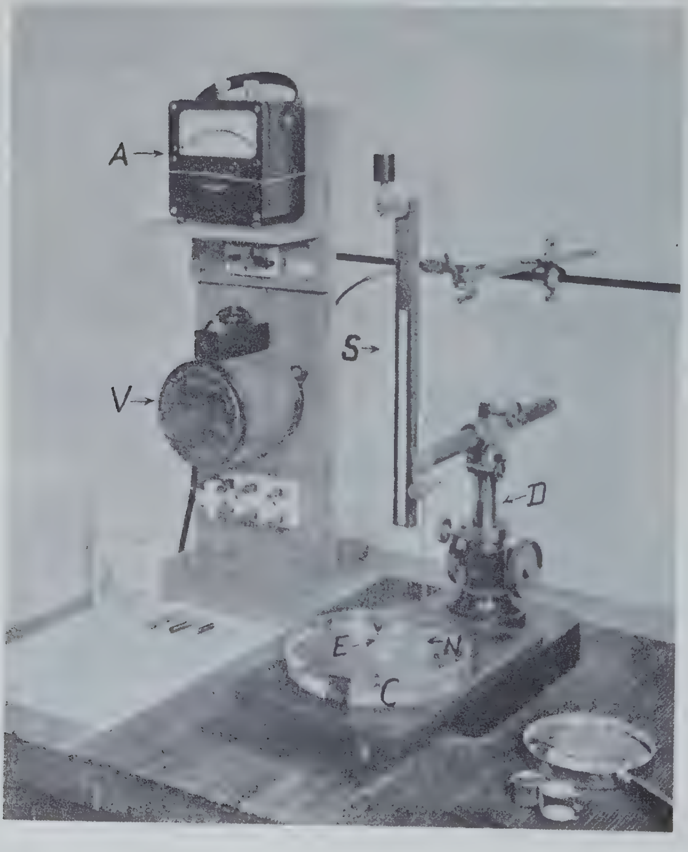

Fig. 1. Apparatus for electrolytic drilling.

The electrolytic method described in this paper for drilling diamond makes use of the Wehnelt[1] electrolytic interrupter for the production of high frequency oscillations. Reference to Wehnelt's work is made by Starling[2] in his discussion of high frequency oscillations. Dawihl and Fritsch,[3] using this electrolytic method to obtain high frequencies, produced hemi-spherical holes about 0.30 mm. in diameter and 0.25 mm. deep in the surface of diamonds with sulfuric acid as the electrolyte. Some of the early experiments with electrolytic drilling at the National Bureau of Standards gave conical holes, .002″–.003″ deep, having small diameters. As a result of further extensive investigation, secondary cones .005″–.006″ deep are now drilled electrolytically in about one hour, with the equipment shown in Fig. 1. This consists of the following parts:

Electrodes, *E* and *N*: 70% Pt.–30% Ir wire, .020″ diameter.
Helical Spring Suspension, *S*: and holder for the drilling electrode.
Device, *D*: for raising, lowering, and rotating the drilling electrode, *E*.
Variac, *V*: 0-135V output.
Ammeter, *A*: 0–1 or 0–2 ampere range.
Glass Container, *C*: for the electrolyte.

Electrode *E* is electrically connected through spring *S* to one output terminal of variac *V*; electrode *N* is connected through ammeter *A* to the other output terminal of the variac.

Factors that affect drilling include (*a*) composition and shape of the electrode, (*b*) composition and concentration of the electrolyte, (*c*) load on the drilling electrode, (*d*) applied potential, (*e*) current, and (*f*) electrical characteristics of the circuit.

From tests of 40 electrolytes including acids, bases and salts, potassium nitrate (KNO_3) was found to be the most satisfactory for drilling secondary cones. Most electrolytes give cones having contour *A*, Fig. 2, in contrast to the more desirable shape for small die cones, *B*, produced with KNO_3. Sodium chloride (NaCl) gives a shallow, funnel-shaped hole, *C*, that has useful applications in making electrolytically drilled dies.

In preparing dies for electrolytic drilling the primary cone should terminate .005″–.006″ from the back surface of a "flat-back" die or from the spherical surface of a "spherical-back" die. NaCl is used for the first drilling of the secondary cone. This gives a shallow, wide-angle cone that blends nicely with the primary cone and places the apex exactly on the axis. The second drilling is made with a solution of KNO_3 which produces a long, small-angle secondary cone having a fair surface polish. The procedure for drilling the secondary cone is as follows:

[1] Wehnelt, A., *Elektrotechn. Zeitschr.*, **20**, 76 (1899).

[2] Starling, Sydney G., *Electricity and Magnetism*, 2nd Edition (**1916**), p. 445.

[3] *Zat. Ver. Deut. Ing.*, **85**, no. 11, 265–268 (Mar. 15, 1941).

Drilling with NaCl.

The drilling electrode is ground with 10°–12° taper to a .002″–.003″ diameter tip. The diamond, previously cemented on a glass pillar in the container, is placed beneath and in line with the axis of the electrode. The electrode is first lowered until it contacts the bottom of the primary cone and is then lowered an additional 3 mm., giving a pressure of about 0.2 gm. on the diamond. A 5 per cent by weight aqueous solution of NaCl is then poured into the container until the die is immersed sufficiently (about 2 mm.) to give 0.6 ampere when 90 volts are applied to the circuit. The non-drilling electrode should dip about 7 mm. beneath the surface of the liquid. Drilling with 90 volts potential is continued for 30 minutes.

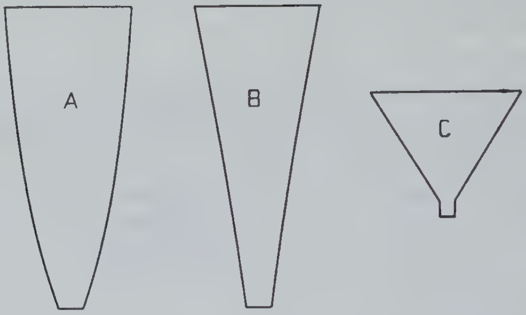

FIG. 2. Contour of cones with different electrolytes: *A*, with several electrolytes; *B*, with KNO_3; *C*, with NaCl.

Drilling with KNO_3.

The procedure for the second drilling operation is similar to the preceding one. The electrolyte in this case is a 10 per cent by weight aqueous solution of KNO_3 and the tip diameter of the drilling electrode is .0010″–.0015″. Voltage and current values are 90 volts and 0.6 ampere respectively. An occasional rotation of the electrode during the drilling tends to improve the contour of the cone.

If the initial distance to be drilled does not exceed .006″, the die will be pierced with a 40–45 minute drilling, giving a smooth-bore cone having a diameter of .0005″–.0006″ at its orifice. If the distance to be drilled is greater than .006″, an additional 40 minute drilling may be required. By controlling the weight applied to the drilling electrode, cones having diameters from .0006″ to .0015″ are produced by this method, Fig. 3 shows a .0007″ diameter cone drilled by the above procedure.

Countersinking the orifice.

The sharp edge formed where the secondary cone meets the back surface is given a slight countersink or chamfer to prevent damage by chipping when wire is drawn through the die. This is accomplished by inverting the die beneath the electrode and then drilling with a 5 per cent solution of NaCl. The electrode for this operation is ground with 30° taper to a fine tip which is inserted in the orifice. Sufficient countersink or relief is obtained in 5 minutes using 70 volts and 0.5 ampere.

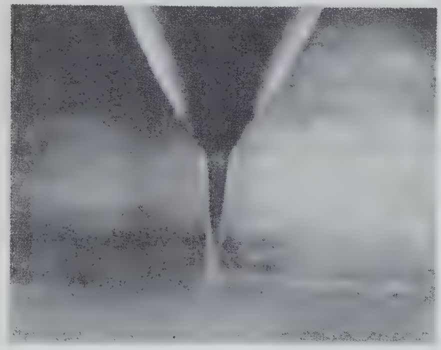

Fig. 3. Electrolytically drilled secondary cone. ×73.

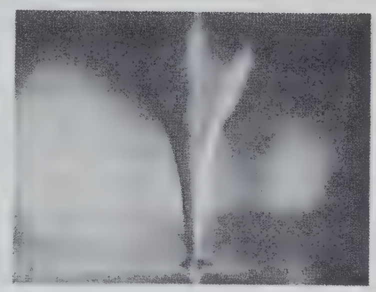

Fig. 4. A well-formed and well-finished .001″ die. ×73.

The cone surfaces of electrolytically drilled cones are usually quite smooth and round and give fair performance in drawing wire. It has been found, however, that die life is materially increased if the secondary cone and bearing are given a high mechanical polish. Fig. 4 shows a die having an excellent primary cone, secondary cone, bearing, countersink and finish.

In conclusion it can be stated that the conditions for drilling are not critical:—excellent results are obtained by die makers after a few hours of instruction. The procedure is neither tedious nor confining and one person can operate several drilling units. Wire-drawing tests indicate that these electrolytically drilled dies are equal or superior to those drilled mechanically.

(10) DEVELOPMENTS AND TRENDS IN THE USE OF INDUSTRIAL DIAMONDS

Chester B. Slawson, *University of Michigan, Ann Arbor, Michigan.*

Ten years ago the important uses of industrial diamonds were in core drilling bits and in tools for dressing grinding wheels. In the previous fifty years, only one important change took place in the industry, the replacing of carbonado by bort diamond in core bits. In most tools, the virgin crystals were mounted in metal in random orientation in the condition in which they were found when mined. Only a few thousand carats were used annually in a processed or fabricated form. These were used chiefly as wire dies, although some few were used as cutting tools. Industrial diamonds were a by-product of gem diamond mining, and the demand did not equal the supply. Hence, large stocks of industrial diamonds had accumulated, and fortunately, too, because the allied powers were able to draw upon them to meet the increased war-time demands.

Today the potential consumption of industrial diamonds far exceeds the ability to produce. In those mines in which large quantities of the lower qualities of diamonds are produced, gem diamonds now are a by-product of industrial diamond mining, and this may bring significant changes in the marketing and control of gem diamonds. This change in the industrial diamond position has been due to the war-time development of the impregnated diamond grinding wheel. By processing a hitherto worthless variety of diamond, an abrasive diamond grit has been produced. During the last year of hostilities, approximately nine million carats of bort diamonds were crushed and sized for introduction into impregnated wheels in this country alone. A number of concerns have experimented with the use of diamond grits in the manufacture of core drilling bits and the adaptation of the larger grit sizes to dressing tools. Such developments would be in keeping with the trend of the last few years towards the use of more and smaller diamonds in core bits and the use of several small diamonds instead of a single crystal in dressing tools.

The processing of diamond calls for the application of crystallographic principles and a knowledge of the properties of a *single crystal*, as distinguished from multicrystalline substances such as metals, alloys, and ceramic products. Such a knowledge is essential in the manufacture of abrasive diamond grit because the rupture of the crystal is dominated by its perfect cleavage. The efficient production of a uniform sized grit, free from elongated splinters and thin plates, cannot be attained without an understanding of the role of cleavage.

Although the production of diamond grit has overshadowed, in terms of carats used, other recent developments, war-time needs made it necessary to produce large numbers of sharp pointed diamonds for the contour shaping of the face of grinding wheels. This was especially true for the small diamonds known as *thread dressers* used in shaping thread grinders. Formerly selected diamond crystals with natural sharp points were used but the supply was inadequate and it was necessary to process or lap such points. While many of these points were produced by mechanically bruting or wearing down the surfaces, a more efficient method is to utilize the methods of the gem diamond cutter.

While the diamond cutter uses empirical methods for arriving at the proper directions for cutting and polishing flat surfaces, it is possible to establish crystallographic principles by which the most efficient direction of lapping any given surface upon the diamond can be found. Those directions in which the diamond will readily take a high polish are often called the "polishing grains."

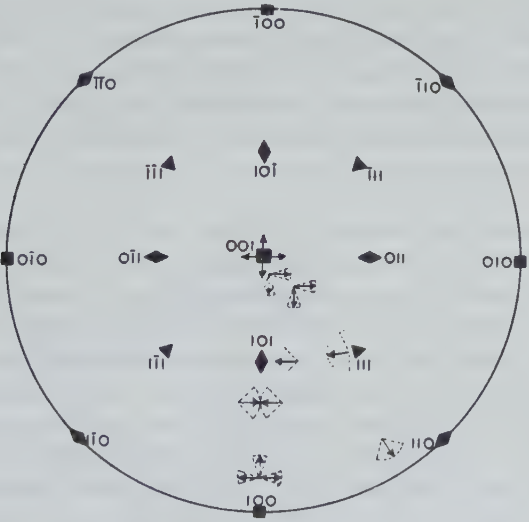

FIG. 1.

There are four polishing grains associated with each possible cube face and two with each dodecahedron, making a total of forty-eight. The diamond cutter refers to these as the four-point and two-point polishing grains, respectively. Because of the symmetry of the diamond, the polishing directions for a facet upon any part of the surface of a diamond may be deduced from those shown in projection in Fig. 1. The direction in which the lap should move across the surface is indicated by the arrows. The allowable deviation from the most efficient polishing direction is represented by sectors of circles. The rate of polishing decreases rapidly as the limiting directions are reached. The following rules will establish the polishing direction or directions at any point upon the surface of the diamond:

The polishing direction is always normal to the zone of the nearest cube and dodecahedron faces.

If the facet lies nearer the cube face, the polishing direction is away from that zone.

If the facet lies nearer the dodecahedron face, the polishing direction is towards that zone.

If the facet lies nearer to the cube face, there will be a second and inferior polishing direction. It will be normal to and directed away from the zone of the cube face and the second nearest dodecahedron.

While it is desirable to utilize the softer directions of the crystal in producing the tool, it is equally desirable to use the hard direction when the tool is put into use. The advantages to be derived from the proper crystallographic orientation of the working surface of the tool have been presented earlier on this program. Because hardness is a vector property, the reverse direction along a soft or polishing direction will be a hard or resistant direction. There are also on every flat surface some directions which are always resistant, irrespective of the sense along which one moves.

One often sees the statement that the cube face is softer than the dodecahedron, or vice versa. Such statements are meaningless, because there are hard and soft directions on both of these surfaces. It is, however, generally recognized that the soft direction of the dodecahedron face is softer than the soft direction of the cube face. Likewise, because there is no polishing direction on an octahedral surface, it is recognized as the hardest surface on a diamond crystal. There is insufficient data available to allow one to draw any conclusions with respect to the comparative resistance of the hard direction of the cube face to that of the dodecahedron, or the comparative hardness in various directions across the octahedron.

The wider recognition of the principles outlined above should lead to a greater use of shaped diamond tools. The necessity in the past of paying the high wages of the gem diamond cutter to perform the simpler operations of tool forming has handicapped their use. The gem cutter, too, is unfamiliar with the fundamentals of tool design. The full utilization of the diamond as a cutting tool must await the time when the tool designer understands the principles of shaping and using the diamond.

The position of shaped diamond tools and the larger diamond wire drawing dies is not as favorable as it was three years ago. These tools require the finer qualities of industrial diamonds, and the price of the rough diamonds rose during war-time above the ceiling prices of the finished tools. It is hoped that with the return of more normal conditions, shaped diamond tools may find their place in the precision cutting of the non-ferrous metals and plastics.

In a few short years the introduction of scientific and technical knowledge has placed the industrial diamond on a sounder footing. We no longer attempt to mechanically drill fine diamond dies with a diamond powder whose coarser particles are larger than the hole we wish to drill. This state of affairs had hardly been rectified by the development of suitable powder before the drilling was being done electrically without its use.

It is an interesting observation that no significant developments in the diamond industry came from within the industry itself. The pre-war status of that industry was one in which the use of the rudimentary tools of science, such as the microscope, was unknown. It was in such an atmosphere that governmental controls and policies were inaugurated in the early days of the war and established on unsound technical grounds. Less than two years ago, an official ruling of the Diamond Section of the War Production Board released the finer qualities of industrial diamonds for cutting into gem-stones on the grounds that they were non-acceptable and undesirable for industrial purposes. The fact that these diamonds, imported from Great Britain at industrial prices, would bring two to three times the import price on the gem market may have had a bearing on this ruling.

The troubles that beset the industrial diamond trade during the war years are perhaps those that are to be expected in an adolescent industry. What the future holds in store for the industry will depend to a great extent upon the availability and the prices of the various grades of industrial stones. For the immediate future, we face the prospect of a shortage in raw material. It must be remembered, however, that this shortage is not due to a falling off of supply, but to a many-fold increase in demand which has arisen through the development of a sounder diamond technology.

MEMORIAL OF FLORENCE BASCOM

Eleanora Bliss Knopf, *New Haven, Connecticut.*

When I think of a long line of revered New England scholars, there comes uppermost in my mind the cultured and upright, albeit slightly austere, personality of Dr. John Bascom, one time President of the University of Wisconsin.

In his early days at Williams College, Massachusetts, there was born to Professor Bascom and his wife, Emma Curtis, on July 14, 1862, a daughter Florence, who was destined to become the pioneer woman geologist on the North American continent. This daughter was indeed destined to be the pioneer in many things. She began her long and distinguished career by being the first woman to receive the degree of doctor of philosophy from The Johns Hopkins University. To Miss Bascom's students her early years were little known, but the strong influence of her father was always manifest in her frequent allusions to him. The ethics and ideology of the quiet but forceful exponent of philosophy in the halls of Wisconsin University and of Williams College was clearly also her approach to the problems of life.

During her father's regime at the University of Wisconsin Florence Bascom graduated there in 1882 with the degrees of A.B. and B.L. Her tendencies toward a scientific career were becoming evident when she acquired the B.S. in 1884 and the A.M. in 1887. As her uncompromising and rigid adherence to high moral standards and her ethical integrity were clearly inculcated by the strong character of her father, so were her scientific training and viewpoint obviously the results of the strong and inspiring influence of her great teacher Van Hise who, in her early years, was one of the master minds of American geology.

Her love of the budding science of petrology had already asserted itself and from Wisconsin she went to The Johns Hopkins University to carry on her advanced research under the father of American petrography, George Huntington Williams, whose brilliant work on the intrusive and volcanic rocks of Maryland has stood the test of time, undimmed and unimpaired. Undeterred by the fact that in those days a field training in geology was not considered part of a ladylike curriculum, Miss Bascom made numerous trips with Professor Williams into the fascinating and complicated terrane underlain by the Precambrian basement rocks of Pennsylvania and Maryland, and when he handed over to her investigation the well-nigh unrecognizable, ancient volcanic flows of South Mountain she turned out, in 1893, a brilliant doctoral dissertation, which placed her at once among the foremost of American petrographers.

Florence Bascom
1862–1945

Upon completion of her work at The Johns Hopkins she became instructor for two years at Ohio State University. In 1895 when President M. Carey Thomas, with her peculiar flair for recognizing young and budding genius, was scouring the United States for promising young instructors, later to become Presidents of the United States, National Academicians, and occupants of honored chairs in the foremost institutions of learning in this country, she prevailed upon the young Florence Bascom to come to Bryn Mawr College to establish a Department of Geology for women,—a somewhat bold experiment, as the feminine skirt still trailed the ground and only the women cyclists were blazing the way in the eastern United States to an outdoor life for women.

The success of Miss Bascom's efforts at Bryn Mawr is shown by the number of her students who later attained prominent positions in University teaching, in State and Federal Surveys, and during World War II in confidential work of avowed military importance in the Military Geology Unit of the United States Geological Survey.

In 1896 Miss Bascom again broke tradition by becoming the first woman assistant on the United States Geological Survey. The field of operation assigned to her by the Survey was the study of the crystalline schists in an area of one square degree, embracing the eastern part of Pennsylvania and Maryland, and a small area in northwestern Delaware. To this was added the crystalline schists in the area of the Trenton folio in New Jersey. Thus for many years she combined with her teaching program, active and energetic field and laboratory work for the Survey, resulting in a series of comprehensive reports comprised in geologic folios and bulletins of the United States Geological Survey.

In 1907 her dominant interest in petrography and mineralogy led her to spend a leave from Bryn Mawr studying advanced crystallography in the laboratory of Victor Goldschmidt at Heidelberg,—a year delightful to her in its opportunity for undisturbed research. However the broad scope of her teaching program effectually saved her from any possible temptation to overspecialistic research and those students who were fortunate enough to enjoy her elementary course in physical geology will testify to her breadth of interpretation of the earth sciences.

Geomorphology was to her a fascinating subject and particularly in later years she contributed much valuable material to the somewhat heated controversy as to the origin of the Eastern Appalachian erosion surfaces. Her writing was always exceptionally vigorous and incisive. She had little patience with pedantic phrases either in conversation, in oratory, or in writing, and her own conversation was forceful and clear cut, even at times somewhat caustic. An untiring, if at times tired, and conscientious worker, she belonged to a rapidly vanishing time when a young field geologist on an assignment for the United States Geological Survey was expected to be in the field by seven in the morning, not to return under ordinary circumstances until six o'clock at night, subsequently to devote the evening to drafting and map work. Well do I remember the vigorous negation when, as a youngster covering the Reading Hills on foot to map the igneous geology, I suggested to Miss Bascom that by starting in the morning as late as half past seven I and my coworker could get a substantial breakfast in our hotel at seven o'clock instead of picking up a poor snack in an overnight hash-house at six thirty! That was not the way that field geology was handled, and I have many times since been grateful for the vigor of my early training that took long hours as a matter of course.

In 1932 Miss Bascom retired from her professorial position at Bryn Mawr and moved to Washington, D. C. where she spent several years in the preparation of final Survey reports. In 1924 she was elected to the Council of the Geological Society of America, the only woman who has ever sat upon this governing board. In 1930 she was further honored by being elected Vice President of that organization. In the late thirties failing health compelled her to remain all year in Williamstown, Massachusets, close to her beloved summer home on Hoosac Mountain, which had been for many years a haven of refuge to her as well as to her much loved animal companions, her horses and her collie dog.

Her life passed out in Williamstown on June 18, 1945, leaving to her colleagues, her students, and her friends the inspiring memory of a scholarly and brilliant mind combined with a forceful and vigorous personality.

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MEMORIAL OF ALEXANDER EVGENIEVICH FERSMAN

L. J. Spencer, *Formerly Keeper of Minerals in the British Museum.*

The Russian Academician A. E. Fersman, whose name was added in 1937 to the short select list of Correspondents of the Mineralogical Society of America, died at Sochi on the Black Sea on May 20, 1945, at the comparatively early age of 61. With the death of Academician V. I. Vernadsky (1863–1945) earlier in the same year, Russia has been suddenly deprived of her two most prominent and energetic mineralogists and geochemists.

Fersman was born at St. Petersburg on November 8 (October 27, old style) 1883, but his early years were spent in the south of Russia. While at the high school at Odessa he had developed a keen interest in minerals, and he therefore went in 1901 to the mining academy at Novorossiysk (Ekaterinoslav). In 1904 he entered Moscow University, where he was a pupil of V. I. Vernadsky, whose influence is clearly shown in all his later work. His first paper in 1904 was on the crystallography of some organic compounds, followed in 1905 by a list of Crimean minerals in the Simferopol museum.

In 1907 he went abroad, working in Paris under A. Lacroix, and in Heidelberg under H. Rosenbusch and Victor Goldschmidt, and travelling in Italy and Switzerland. At Heidelberg, in collaboration with Goldschmidt, elaborate work was done on the crystallography of diamond, the results being published in "Der Diamant" (Heidelberg, 1911), a handsome volume of 291 pages with 206 text-figures and 43 plates. The coloured plates give excellent illustrations of the light-figures reflected from the curved surfaces of the crystals. Incidentally, the title-page of this volume gives the name of the first author as A. von Fersmann: but there is no reference to such a title in any of his many Russian publications. The early part of his extensive work on Russian zeolites and on the minerals of the palygorskite group appears to have been done in Paris. During this period he also produced a 46-page paper on the mineralogy of the island of Elba. This was the beginning of his extensive researches on pegmatites during many subsequent years.

Returning to Russia in 1910, he took a large part in organizing the Peoples' (Shanyavsky) University in Moscow, where he was the first professor of mineralogy, giving here his first lectures on geochemistry. In 1912 he was professor in the girls' high school (Bestuzhevsky) in St. Petersburg, and also an assistant under Vernadsky in the mineralogical museum of the Academy of Sciences. Later he was for a time professor of mineralogy and crystallography in the University of St. Petersburg. On

1883–1945

his election as Academician in 1919, he became director of the museum, which was reorganized in 1930 as part of the Lomonosov Institute, including mineralogy, geochemistry, and crystallography, and was transferred to Moscow in 1934.

The Academy of Sciences of the U.S.S.R. has a bewildering number of sections and branches, committees, commissions and councils, institutes laboratories, museums, libraries, scientific societies and journals, all engaged in intensive scientific research. In many of these Fersman was a driving force: his activities were not confined to the Lomonosov Institute. He was also director of the Geographical Institute and of the Khibina Research Station in the Kola peninsula, and was closely connected with the institutes of archaeological technology, history of cultural relations, aerophotography, optics, radium, hydrology, ceramics, soils, etc., etc. Furthermore, he was responsible for controlling and editing much of the voluminous literature published by the Academy.

Even all this was not enough to satisfy the man's dynamic energy. After the war of 1914–18 and the revolution of 1917, he realized and persistently insisted upon the importance of developing the country's natural resources, specializing more particularly in the mineral resources. Numerous expeditions were organized, many of them led by himself, to the Urals, Crimea, Caucasus, Kazakhstan, Turkestan, Altai Mountains, Transbaikalia, northern Mongolia, Karelia, and the Kola peninsula, etc. Large deposits of native sulphur were discovered in the Kara-Kum desert east of the Caspian Sea, and deposits of uranium and vanadium ore at Tyuya-Muyun in Fergana.

The intensive exploration and investigation of the alkalic rocks of the Khibina and Lovozero tundras in the Kola peninsula was commenced in 1920. There in the uninhabited and desolate region within the Arctic Circle this work led to a prosperous industry. Already in 1934 the new town of Kirovsk had a population of 40,000. The vast deposits of apatite-nepheline-rock have been worked for apatite, while the separated nepheline has been used in the manufacture of aluminum, soda and potash, and in the ceramic industry. Deposits of pyrrhotine (for sulphuric acid) and molybdenite have also been worked. Rich concentrations of minerals containing rare-earths, titanium, zirconium, and uranium have been found; and many new minerals have been discovered, including one to which the name "fersmannite" has been given (*Am. Mineral.*, **16**, 92). "Minerals of the Kola Peninsula" is the title of a paper contributed by Fersman to this journal in 1926 (vol. 11).

Ever since his early visit in 1909 to the island of Elba, Fersman was especially interested in pegmatites and the paragenesis of the rarer minerals that are concentrated in them. At every opportunity he visited localities where they occur in the Urals, Transbaikalia, Karelia, Kola, etc. Numerous papers resulted, giving his views on their genesis and classification. The successive stages in their formation he recognized as: magmatic (900–800° C.), epimagmatic (800–600°), pneumatolytic (600–400°), hydrothermal (400–50°), and hypogemic (50–0°). His book "Pegmatites, vol. 1, Granite-pegmatites," published in 1931, reached a third edition in 1940. A second volume on the syenite-pegmatites of alkalic rocks of the Kola type was in preparation. In addition to this work on pegmatites in general, another series of volumes was started in 1936 under his editorship on "Pegmatites of U.S.S.R.," giving detailed accounts for each district.

It was evidently this work on pegmatites that led Fersman to his intensive work on geochemistry by which he is best known. He enquired why certain chemical elements and minerals were accumulated in certain places in the earth's crust, and by formulating hypotheses he was able to predict in some cases where minerals of economic value would be found. Some of his views are highly speculative and difficult to follow: he talked of "clarkes" (named after F. W. Clarke, the author of "The Data of Geochemistry"), energetics, "eks" and "veks" and "paragenes," and branched off into topogeochemistry, biogeochemistry, and cosmochemistry. His first book on this new subject was "Geochemistry of Russia" of which volume 1 was issued in 1922 and two further volumes were promised. But this gave place later to a more general work, "Geochemistry," which appeared in four volumes (1933–39), with a second edition of volume 1 in 1934. Other books are "Chemical Elements of the Earth and the Cosmos" (1923); and "The Search for Mineral Deposits on the Basis of Geochemistry and Mineralogy" (1939); and a further one "Mendeleev's Periodic Law and Geochemistry" was promised.

Another side-line arising out of his study of pegmatites was that of precious stones, here again starting from the tourmalines of Elba. In addition to those occurring in the pegmatites of the Urals and Transbaikalia, he made detailed examinations of the emerald mines in biotite-schist of the Urals, and of lapis-lazuli in metamorphic limestone near Lake Baikal. A book "Coloured Stones of Russia" (vol. 1, 1921) was superseded by "Precious and Coloured Stones of U.S.S.R." (vols. 1 and 2, 1923 and 1925). Detailed accounts were given of the "Orlov" and "Shah" historical diamonds, and he was joint author of a large volume on the Russian crown jewels. (This I have never been able to see: a German catalogue mentions 100 plates and the price 350 Marks.) He also wrote on the working of precious and ornamental stones in the Ekaterinberg (now Sverdlosk) factories; and still another offshoot was a booklet dealing with the causes of colour in minerals.

Another very ambitious series of volumes was to be on the topographical mineralogy of the U.S.S.R., of which "Mineralogy of the Urals" (vol. 1, elements and sulphides) appeared in 1941 under his editorship. "Geochemists' and Mineralogists' Companion" (1937) is a useful book of reference containing a compilation of miscellaneous data.

To crown all this solid scientific work, he prepared many popular booklets expounding the practical results and inspiring the general public (and no doubt also those in authority who held the purse strings). His well-illustrated "Entertaining Mineralogy" first appeared in 1928 (5th edition, 1937) and was translated into German (Leningrad, 1931). "Three Years Beyond the Arctic Circle" (1924) gave an account of the early work in the Kola peninsula. "Reminiscences about Minerals" (1945) was written in Praha, Bohemia, during a spell of illness brought on by overwork. Others were fortunately translated into English: "The Scientific Study of Soviet Mineral Resources" (International Publishers, New York, 1935, but printed in Russia); "Twenty-five Years of Soviet Natural Science" (Moscow, 1944); "The March of Soviet Science" (London, 1945).

It is really surprising the amount of work that the man got through. His energy and enthusiasm were unbounded, and he evidently possessed the faculty of inspiring the same qualities in a devoted band of followers and research workers, including several women who were also prolific authors of mineralogical papers. With the constantly overflowing and overcrowding of new ideas, much of his work remained unfinished.

Lengthy appreciations of Fersman's work had been given only shortly before his death: "The Life and Scientific Work of Academician A. E. Fersman (for his 60th birthday)," by B. M. Kupletsky, *Bull. Acad. Sci. URSS*, Sér. Géol., 1944, No. 1, pp. 35–42, with portrait (here reproduced); "Alexander Evgenievich Fersman as a Mineralogist," by N. A. Smolyaninov, *ibid.*, pp. 42–48; "The Geochemical Works of A. E. Fersman," by A. A. Sankov, *ibid.*, pp. 49–57. In 1940 a booklet was issued by the Academy of Sciences giving a bibliography (679 entries!) of his writings for the period 1904–40, together with a short biographical sketch and a portrait.

Unfortunately I never had the opportunity of meeting Fersman personally, but since 1922 he had generously sent me many of his books and papers. I therefore conclude with the following account of his personality, which was written in English in the "Moscow News" of May 25, 1945, by his colleague the veteran geologist Academician V. A. Obruchev: "It is difficult to believe that Academician Alexander Fersman is dead.

We always knew him as such a vigorous, buoyant, optimistic person. To say that an outstanding scientist has departed from us would be insufficient. We have lost a big man, a man tireless in work and in quest, a man with a limitless range of interests and boundless potentialities and talent, a trail-blazer in science, fine orator and popularizer, and with the priceless gift of infecting those around him with his dynamic energy and enthusiasm."

MEMORIAL OF EDWARD WIGGLESWORTH

CHARLES PALACHE, *Harvard University, Cambridge, Massachusetts.*

The death of Edward Wigglesworth on May 6, 1945 brought to an untimely close a life unselfishly devoted to mineralogy and its related sciences. Few members of our Society have joined to the responsibilities of large means and inherited business affairs such varied and burdensome scientific occupations.

Wigglesworth was born in Boston in 1885 in a family with traditions reaching far back to colonial times. He was the seventh successive member of the family to bear the name of Edward. He entered Harvard in 1904 and, coming early under the influence of the late Professor Woodworth whose summer field courses attracted many young students into his science, he concentrated in Geology and graduated in 1908. He received the A.M. degree in the following year and in 1910 associated himself with the Harvard instructing staff by accepting the Curatorship of the Gardner Collection of photographs, an honorary position which he held for seven years. From 1911 to 1915 he was also Assistant in elementary geology courses under Professor Woodworth.

Wigglesworth's early interests were in Petrology and Glacial Geology. With the late Professor Wolff he studied the serpentine rocks of Vermont, a field and laboratory study, published in 1915. With Woodworth he devoted several field seasons to the study of the geology of the Island of Marthas Vineyard. This work was finally developed into a thesis, presented in 1917, for the degree of Ph.D. It was not published until many years later. Woodworth's glacial studies of the southern New England region were collected and edited by Wigglesworth after Woodworth's death in 1925, and the thesis became an important part of the volume published in 1934 as a Memoir, No. 52, of the Museum of Comparative Zoölogy at Harvard under joint authorship.

Meanwhile Wigglesworth became interested in Mineralogy. In 1914 he became Honorary Custodian of Mineralogy for the Boston Society of Natural History. He established an office in the Museum building on Berkeley Street and gave a large part of his time for many years to the improvement and increase of the mineralogical and geological collections. In 1919 he became Director of the Museum, now known as the New England Museum of Natural History, and so remained until 1940. His principal aim during his long Directorship, so far at least as regards the mineral collection concerning which the writer was not infrequently called into consultation, was to transform it from a general display of minerals into a strictly New England collection. He exchanged

EDWARD WIGGLESWORTH
1885–1945

most of the materials on exhibition which were derived from sources outside of New England for those of local origin. He purchased with his private means several local New England collections and many individual specimens; he rearranged and recased these in an attractive way and succeeded in gathering together a very remarkable display of the products of New England's mines and quarries. He particularly improved the display of gem minerals, both cut and uncut, sparing no expense or time to make it complete.

It was the difficulties Wigglesworth encountered in thoroughly identifying his cut stones that led him into his last and perhaps most absorbing mineralogical study, that of Gemology. He took the courses established by the American Gem Society for the identification of gems by optical and physical tests and became a certified Gemologist in 1939. He organized a series of loan exhibitions of gems at the Museum with the coöperation of Boston jewelry firms. He became closely associated with Robert M. Shipley, Jr., founder of the Gemological Institute of America in Los Angeles; he established a New England center of the Institute in Boston, where he taught many students of the subject; and on withdrawing from the New England Museum in 1940 he opened an office on Newbury Street as the eastern headquarters of the Institute. At the time of his death he was President of the Institute and Secretary of its Examination Board. With Mr. Shipley he compiled a dictionary of gems and gemology. Thus his personality and influence was known to a country-wide group of gem students and dealers.

Wigglesworth kept up an association with his Harvard teachers and friends by accepting membership in the Visiting Committee for the Geological Sciences through the years 1919–1945. He was a faithful attendant at the committee's annual meetings and maintained an active interest in the development of the Division and particularly in the Mineralogical Museum.

He was a charter member of the Mineralogical Society of America, became a life Fellow in 1925 and was Vice-President in 1929.

Dr. Wigglesworth endeared himself to his many friends by his simplicity and charm of manner. He was all too humble in estimating his very real accomplishments, insisting, as he always did, that he was but an amateur in the mineralogical field. The science has lost by his death an able worker and the Society a worthy and valued member. The writer mourns the loss of a tried and true friend. Our acquaintance began when he was an undergraduate in the elementary course in Mineralogy and it ripened into a lasting friendship.

PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA AT PITTSBURGH, PENNSYLVANIA

C. S. HURLBUT, JR., *Secretary*

The twenty-sixth annual meeting of the Society was held at the Hotel William Penn, Pittsburgh, Pennsylvania, on December 27–29, 1945. The registration figures show that 74 fellows and 56 members attended. Four scientific sessions were held, two in the afternoon of December 27th and two in the afternoon of December 28th. Because of lack of time the routine business of the Society was not presented at a general session. The luncheon of the Mineralogical Society, which was held on December 27th, was attended by 108 fellows, members and guests. After the luncheon the Society was addressed by Past Presidents R. C. Emmons on "The Shift in Emphasis" and A. F. Buddington on "Some Mineralogical Reflections."

The report of the election of officers and fellows for 1946 and the reports of the officers for the year 1945 are given on the following pages.

ELECTION OF OFFICERS AND FELLOWS FOR 1946

The secretary reports that 343 ballots were cast for the officers of the Society as nominated by the Council.

The officers for 1946 are:

President: Paul F. Kerr, Columbia University, New York City.
Vice-President: S. B. Hendricks, Bureau of Plant Industry, U. S. Department of Agriculture, Beltsville, Maryland.
Secretary: C. S. Hurlbut, Jr., Harvard University, Cambridge, Mass.
Treasurer: Earl Ingerson, Geophysical Laboratory, Washington, D. C.
Editor: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.
Councilor (1946–49): Joseph Murdoch, University of California at Los Angeles, Los Angeles, California.

The secretary reports that according to the provisions of the constitution the following have been elected to fellowship:

Cannon, Ralph S., Jr., U. S. Geological Survey, Washington, D. C.
Gabriel, Alton, U. S. Bureau of Mines, College Park, Maryland.
Haff, John C., Colorado School of Mines, Golden, Colorado.
Heyl, George R., U. S. Geological Survey, Washington, D. C.
Larsen, Esper S., 3rd, U. S. Geological Survey, Washington, D. C.
Lausen, Carl, U. S. General Land Office, Albuquerque, New Mexico.
Macdonald, Gordon Andrew, U. S. Geological Survey, Honolulu, Hawaii.
Mason, Brian Harold, Canterbury College, Christchurch, New Zealand.
Moneymaker, Berlen C., Tennessee Valley Authority, Knoxville, Tennessee.
Pecora, William Thomas, U. S. Geological Survey, Washington, D. C.

CHANGE IN THE BY-LAWS OF THE SOCIETY

The following change in Article IV, Section 2 of the By-Laws of the Society was approved by the general membership:

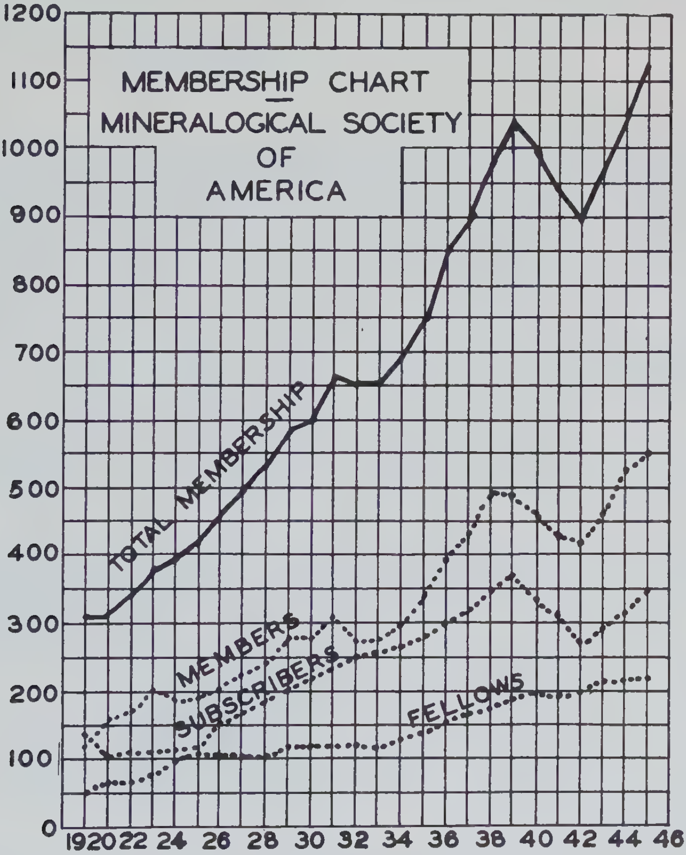
From

The list of nominations for fellowship in the Society shall be sent to the fellows at the same time as the nominations for officers. Five opposing votes shall be considered as rendering a candidate ineligible for fellowship.

To

The list of nominations for fellowship in the Society shall be sent to the fellows at the same time as the nominations for officers. If ten per cent of the fellows voting on a given candidate cast opposing votes, the candidate shall be considered ineligible for fellowship.

REPORT OF THE SECRETARY FOR 1945



To the Council of the Mineralogical Society of America:

Membership Statistics

	1944	1945	*Gain*	*Loss*
Correspondents	6	5	—	1
Fellows	211	218	10	3
Members	522	549	127	100
Subscribers	313	344	39	8
	1052	1116	176	112

The above figures show a loss of one correspondent and a net gain of 7 fellows, 27 members and 31 subscribers, giving a total gain for 1945 of 64. This brings the grand total to 1116, and thus for the second consecutive year a new high record is set. The chart showing the trend in membership in the Society has been brought up to date and accompanies this report.

The Society lost through death in 1945 two fellows, Florence Bascom and Edward Wigglesworth, as well as A. E. Fersman, a correspondent from the Soviet Union.

Respectfully submitted,
C. S. Hurlbut, Jr., *Secretary*

REPORT OF THE EDITOR FOR 1945

To the Council of the Mineralogical Society of America:

Despite diversion of manpower to efforts pertaining either directly or indirectly to the war, and restrictions imposed by shortages of labor and materials, the bi-monthly journal has appeared quite regularly, and the overall accomplishments for the year 1945 seem very satisfactory, especially when the various handicaps referred to are taken into consideration.

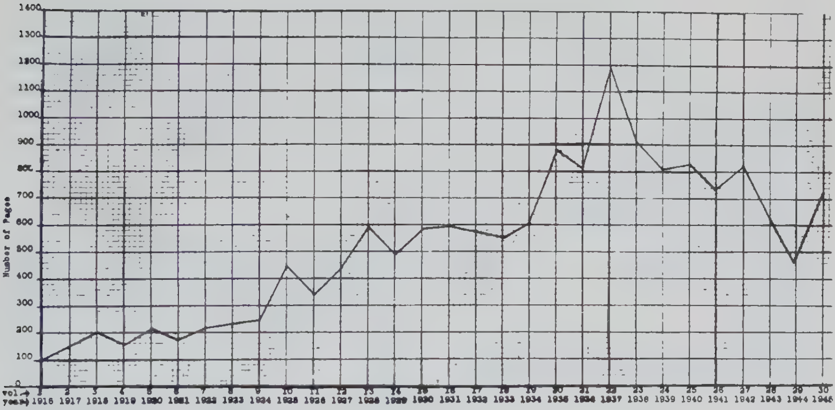
Slight delays in the appearance of the issues and in the distribution of the reprints have no doubt caused some annoyance to a number of our readers and contributors. Even though the war is now over, the printer informs me that the young men formerly in their employ are not returning as rapidly as had been expected. Some of them are availing themselves of the educational program which the government is offering ex-servicemen, and it is impossible to secure new experienced workers. Also, the mechanical equipment is offering difficulty. For the past four years, printing establishments have been unable to replace worn machinery according to a carefully worked out annual replacement program which was in effect before the war. The rate of recovery is bound to be slow for some months to come. However, in time, these various difficulties will be surmounted.

Before attempting an analysis for the year 1945, it may be in order to call attention to two special features of the current volume. As you recall, the May-June number was devoted exclusively to a 264-page symposium of fourteen articles on quartz oscillator-plates. These valuable and timely contributions on the geology of quartz crystal deposits, on the inspection, grading, cutting and testing of thin quartz wafers, were made possible largely through the efforts of Drs. Frondel, Parrish, Gordon, and their associates, to whom the Editor is greatly indebted for assembling the material and reading proof. Likewise, substantial financial assistance was received from the Reeves Sound Laboratories and North American Philips Company to help defray the heavy expense involved in the printing of this unusually large and highly illustrative number. This special issue was very well received, as indicated by the demand for copies from individuals and organizations not on our regular mailing list.

A second feature of interest relates to the insertion of a colored plate in connection with the description of the new mineral brazilianite, that appeared in the September-October issue. In the past, due mainly to the high cost of this type of reproduction, the Society's limited finances did not seem to justify this luxury. However, with some additional assistance from the Geological Society of America, it may be possible in the future to include a very limited number of these plates each year when the subject matter is such as to definitely require and justify such expensive treatment. Recognition and appreciation is here again expressed for financial assistance received during the year from the Geological Society of America to help defray publication costs.

In some quarters the question has been raised, of late, as to when the Journal would again be issued on a monthly basis. Manuscripts are not being received with any degree of regularity or in sufficient numbers to make the change desirable at the present time. Until conditions become more normal, it is the Editor's opinion that a bi-monthly journal of a substantial size creates a far more favorable impression than a thin, anaemic monthly of very limited content.

The current year concludes the thirtieth volume of *The American Mineralogist.* During the past twenty-six years of its existence, the Journal has served as the official publication of the Society. A graph indicating the growth of the Journal during this thirty-year period is not a smooth curve, but the general overall trend is in the desired direction (Fig. 1). The special "Palache Number," financed largely by friends of Harvard University, was responsible for the very high peak reached in 1937.



It may be of some interest to note that during this thirty-year period the Journal has published over 15,700 pages of mineralogic literature. If this total be broken down into five-year periods, we find:

Vols. 1–5 (1916–1920)	816 pages
Vols. 6–10 (1921–1925)	1,318 pages
Vols. 11–15 (1926–1930)	2,448 pages
Vols. 16–20 (1931–1935)	3,216 pages
Vols. 21–25 (1936–1940)	4,552 pages
Vols. 26–30 (1941–1945)	3,364 pages
	15,714 pages

In a detailed analysis of the Journal for 1945, we find that Volume 30 contains 724 pages, exclusive of index. This represents an increase of 268 pages compared with the volume of the previous year. In fact, the present volume compares very favorably with the size of the Journal issued in 1941. Leading articles, which number 51, occupy exactly 90% of the total space. Table 1 which accompanies this report indicates the distribution of the leading articles in the various fields listed. The average length of the main articles is 12.8 printed pages.

If to the leading articles we add 11 shorter papers appearing under the heading of "Notes and News," we obtain a total of 62 published manuscripts for the calendar year. These contributions were received from 62 contributors associated with 41 different universities, research bureaus, and technical laboratories.

The Journal for 1945 carries detailed descriptions of three new minerals: cattierite, vaesite, and brazilianite. Three hundred and three illustrations of various types assist in clarifying the descriptive portions of the text. As in previous years, a number of manuscripts were received from sources beyond our borders, and in 1945 seven such contributions were printed.

The accompanying table of contents summarizes in detail the subject matter of Volume 30.

TABLE 1. DISTRIBUTION OF SUBJECT MATTER IN VOLUME 30

Subjects	*Articles*	*Pages*	*Per Cent of Total*
Leading articles*			
Descriptive mineralogy	4		
Chemical mineralogy	7		
Structural crystallography	5		
Geometrical crystallography	1		
Petrography	3		
Optical mineralogy	2		
Mineralography	2		
Memorials	8		
Miscellaneous	5		
Quartz oscillator-plates (Symposium)	14		
	51	652	90.0
Shorter articles	11	20	10.0
Notes and news	11	4½	
Abstracts of new mineral names	19	4½	
Proceedings of Societies	20	38½	
Book reviews	7	4½	
Total entries	119	724	100.0
Illustrations	303		
Index, Title page, Table of contents		12	
Grand Total		736	

* Leading articles average 12.8 printed pages.

Respectfully submitted,
WALTER F. HUNT, *Editor*

REPORT OF THE TREASURER FOR 1945

To the Council of the Mineralogical Society of America:

Your treasurer submits herewith his annual report for the year beginning December 1, 1944, and ending November 30, 1945.

Receipts

Cash on hand December 1, 1944	$ 5,170.64
Dues and subscriptions	3,565.23
Sale of back numbers	399.11
Authors' charges on separates	117.49
Interest and dividends from endowment	2,599.52
Partial payments on principal of Trenton Mortgage Service Company's preferred stock	367.57
Advertisements	205.04
Geological Society of America Grant for 1945	1,508.49
Refund on postage	4.78
Sale of 20-volume index	3.00
Sale of extra copies of the May-June issue	353.26
	$14,294.13

Disbursements

Printing and distribution of the Journal (6 issues)	$ 4,539.03
Printing and distribution of separates	645.72
To the Editor, Secretary, and Treasurer	830.00
Postage	91.90
Clerical help	289.88
Refunds on subscriptions	6.41
Returned check	6.00
Office equipment	1.30
Telephone and telegraph	9.13
Safety deposit box	9.60
Printing and stationery	184.30
Committee expenses	3.54
Expenses of 25th Anniversary Meeting	11.85
Insurance on Roebling Medal	5.00
Exchange charge on check	.50
New securities purchased	4,987.50
Broker's commission on securities	19.97
Tax on new securities	4.80
	$11,646.43
Cash balance November 30, 1945	2,647.70
	$14,294.13

The endowment funds of the Society as of November 30, 1945, consist of the following securities:

BONDS

5M U. S. Treasury, 2½%	$ 5,190.63
5M Illinois Central, 4%	3,887.50
5M Southern Railway, 5%	5,743.75
5M Cleveland Union Terminal, 5%	5,068.75
6M Atlantic Coast Line, 4½%	5,257.50
4C Great Northern, 5½%	400.00

PREFERRED STOCKS

50 shares, Virginia Electric & Power Co., 5%	5,942.50
55 shares, U. S. Steel, 7%	6,946.20
50 shares, Union Pacific, 4%	4,570.25
60 shares, Jones & Laughlin, A, 5%	4,987.50
10 shares, Consolidated Edison	1,066.64
5 shares, Public Service of New Jersey	702.00
37 514/1000 shares, Trenton Mortgage Service Company	#1,884.62

COMMON STOCKS

50 shares, Chesapeake & Ohio Railway	2,368.75
50 shares, Pennsylvania Railroad	1,468.75
25 shares, Standard Oil of New Jersey	1,356.25
25 shares, American Telephone & Telegraph Company	3,369.32
	$60,210.91

# Residual value

Respectfully submitted,
EARL INGERSON, *Treasurer*

REPORT OF THE AUDITING COMMITTEE

To the President of the Mineralogical Society of America:

The Auditing Committee has examined and verified the accounts of the Treasurer of the Mineralogical Society of America for the fiscal year ending November 30, 1945. The securities listed in the Treasurer's report, with all future coupons on the coupon bonds attached, are in the safety deposit box at the Friendship Branch of the Riggs National Bank of Washington, D. C.

Respectfully submitted,
JOSEPH J. FAHEY, *Chairman*
WILLIAM T. PECORA
CHARLOTTE MARSH

DANA FUND

No disbursements made during the fiscal year 1945. Interest received = $9.32. Available balance, November 30, 1945 = $943.39.

Respectfully submitted,
WALDEMAR T. SCHALLER

ABSTRACTS OF PAPERS PRESENTED AT THE TWENTY-SIXTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA

Presidential Address

GEOLOGICAL MINERALOGY

KENNETH K. LANDES

Mineralogy has by tradition been mainly a laboratory science. But except for further refinements in measurements and analyses we can go but little farther in laboratory mineralogy. Major opportunities for contribution exist in geological mineralogy (paragenesis). This involves combined mineralogical and geological studies in both field and laboratory. Mining geologists have made valuable paragenetic studies of ore deposits. Equally good opportunities for research in geological mineralogy are to be found in other types of deposits including pegmatites, clastic sediments, and chemical sediments.

MANSFIELDITE, A NEW ALUMINUM ARSENATE, AND THE MANSFIELDITE-SCORODITE SERIES

VICTOR T. ALLEN AND JOSEPH J. FAHEY

The name, mansfieldite, in honor of Dr. George R. Mansfield, retired chief of the Areal and Non-metalliferous Section, Geological Survey, U. S. Department of the Interior, is given to a new mineral with the formula $Al_2O_3 \cdot As_2O_5 \cdot 4H_2O$. Mansfieldite constitutes the aluminous end member of an isomorphous series, of which scorodite is the ferric iron end member. Mansfieldite and intermediate members of the series were formed at Hobart Butte, Lane County, Oregon, probably in Miocene time by hydrothermal solutions that reacted with Eocene kaolinitic clay. The arsenates of aluminum and iron form colloform crusts along open cavities in the clay and are associated with realgar, stibnite, pyrite, quartz, siderite, and kaolinite-dickite.

Mansfieldite is white to pale gray, has a vitreous luster, a hardness of about 3.5, a spherulitic or axiolitic structure, and occurs as porous, cellular masses ranging in length from a few centimeters to 20 centimeters. Its specific gravity is 3.031. Its optical properties are: indices of refraction, $\alpha=1.622$, $\beta=1.624$, $\gamma=1.642$; 2V = medium small; optical character, positive; dispersion, $r>v$.

The x-ray patterns of the mansfieldite-scorodite series by Joseph M. Axelrod are strikingly similar and undoubtedly represent isostructural minerals. The optical and x-ray data together with the similar structure of mansfieldite and aluminous-scorodite at Hobart Butte indicate that mansfieldite is orthorhombic. A curve, in which the indices of refraction of mansfieldite and scorodite are plotted with reference to Al_2O_3 and Fe_2O_3, indicates that the chemical composition of any member of the mansfieldite-scorodite series can be determined from its optical properties.

The possibilities of isomorphism between mansfieldite-variscite, mansfieldite-strengite, variscite-strengite, variscite-scorodite, and strengite-scorodite are also discussed.

NONTRONITE IN THE PACIFIC NORTHWEST*

VICTOR T. ALLEN AND VERNON E. SCHEID

Several new occurrences of nontronite have been discovered in Washington, Idaho, and Oregon during the investigation of high-alumina clay by the Geological Survey, U. S. Department of the Interior. The nontronite forms from basaltic glass, palagonite, iddingsite, and augite under conditions of poor drainage in the presence of alkalies or alkaline earths, especially magnesium. Under conditions of thorough drainage in the presence of neutral or slightly acid solutions kaolinite and halloysite form from plagioclase feldspar while nontronite migrates and fills vesicles as well as cracks ranging from a fraction of an inch to six inches in width. From large veins near Spokane, Colfax, and Garfield, Washington, three new nontronites have been analyzed and their optical properties and geologic relationships have been determined.

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* Published by permission of the Director, U. S. Geological Survey.

INVESTIGATION OF THE MICACEOUS MINERALS IN SLATE

THOMAS F. BATES

A mineral of the illite group has been found in the slates from the Lehigh-Northampton district of northeastern Pennsylvania. Identification of the material has necessitated a careful investigation of each of the other micaceous minerals, namely sericite and chlorite.

Froth flotation and supercentrifuge techniques were used to separate the fine-grained micaceous particles from the other minerals in the slate. Pure concentrates of each of the micas could not be obtained.

Optical investigation showed the relation of the micas to the textures and to the other minerals of the slate but did not furnish proof of the presence of an illite mineral.

X-ray diffraction methods served to distinguish chlorite from the other two micaceous minerals but were not satisfactory in differentiating between sericite and illite.

Differential thermal analyses gave endothermal peaks characteristic of an illite mineral and also yielded information as to the nature of the chlorite.

Electron micrographs were used to advantage in the study.

CORNETITE AND PSEUDOMALACHITE

L. G. BERRY

New observations combined with the existing chemical analysis on cornetite from Bwana Mkubwa, Northern Rhodesia, lead to the following description of the mineral: Orthorhombic, dipyramidal with space group $D_{2h}^{15}-Pbca$; the unit cell with $a=10.86\pm0.04$, $b=14.05\pm0.05$, $c=7.11\pm0.02$ kX, $a:b:c=0.7730:1:0.5061$; contains $24CuO\cdot4P_2O_5\cdot12H_2O=8[Cu_3PO_4(OH)_3]$; calculated specific gravity 4.10. Crystals commonly dipyramidal, showing forms $d(210)$, $v(121)$, $n(021)$, $p(221)$; with $(021):(0\bar{2}1)=90°42'$ (calc.). No cleavage observed. Specific gravity 4.10 (Hutchinson and MacGregor). A single crystal of cornetite from Katanga, Belgian Congo, yielded lattice constants in good agreement with the values given above.

Pseudomalachite from Rheinbreitinbach, Germany, dihydrite from Ehl, Germany, and ehlite from Nizhni Tagilsk, Russia, give identical *x*-ray powder patterns which are distinct from the pattern of cornetite.

ARTIFICIAL METAMORPHISM OF MINERALS

M. J. BUERGER

Metamorphic textures imply grain growth. Theoretically, this can be experimentally produced by heating a mineral aggregate containing grains of high energy. Such grains can be provided by plastic deformation. Guided by this theory, many monomineralic aggregates have been experimentally metamorphosed by treating them in the following steps: (1) the aggregate is first plastically deformed by application of intense pressures, (2) the deformed aggregate is heated above a certain critical temperature. Above this temperature, which varies with the crystal species, the aggregate recrystallizes. The grain size increases with the time and temperature of heat treatment. The whole process has been followed by *x*-ray studies, which demonstrate the reality of strain in the plastically deformed aggregate, followed by release of strain and grain growth in the heated aggregate.

INTERNAL STRUCTURE OF GRANITIC PEGMATITES*

E. N. CAMERON, R. H. JAHNS, A. H. McNAIR, AND L. R. PAGE

It has long been recognized that many pegmatite bodies are divisible into lithologic and structural units of contrasting composition or texture, but no classification of these units applicable to large groups of pegmatites has appeared. Recent investigations of pegmatite mineral deposits by the Federal Survey during a period of unusually widespread mining operations gave an exceptional opportunity for detailed structural analysis of pegmatite bodies. Some forty geologists were engaged in this work, chiefly in South Dakota, Colorado, Wyoming, Idaho, New Mexico, the Southeastern States, and New England. Comparisons of findings indicate that certain types of lithologic and structural units are common in pegmatites studied in all districts. The various types will be described and illustrated, and a general classification of pegmatite units will be discussed.

LINEAR ANALYSIS OF A MEDIUM-GRAINED GRANITE

FELIX CHAYES

The design and results of an experimental evaluation of the precision of linear analysis are described. It is shown that no systematic error is introduced by duplicate or multiple measurements of the same grain, providing the traverses are evenly spaced throughout. The precision error, whether of a single linear analysis or of a mean based on a group of such analyses, varies directly with the traverse interval. The mean of a large number of linear analyses will not differ from a true Rosiwal analysis of the same group of slides.

Numerical statements of these conclusions are given for the Woodstock, Maryland, granite as analyzed by the writer on the Hurlbut and Wentworth-Hunt micrometers. The precision error of a single analysis is small in comparison to differences between thin sections; in this case it may be neglected. It is shown by comparison of Hurlbut- and Wentworth-stage results that the precision of the two instruments is of the same order.

MICROANALYSIS BY X-RAY DIFFRACTION

J. D. H. DONNAY

Good x-ray powder patterns have been obtained from polycrystalline samples of low-quartz weighing only a few micrograms. The weight of the smallest sample thus identified was about 0.003 or 0.004 milligram.

CONTROLLED LOW VOLTAGE DRILLING AND REAMING OF DIAMONDS

W. B. EMERSON

An electrolytic method for drilling secondary cones of wire-drawing diamond dies of .0005–.0015″ diameter is described. Excellent cones of .006–.008″ depth and having the correct contour are produced with applied potentials of 90–120 volts in much less time than is required to drill similar cones by customary mechanical procedures. Likewise, the sharp edges formed at the intersection of the bearing and cup cones of a die may be relieved by electrolytic drilling.

MAXIMUM ERROR IN SOME MINERALOGIC COMPUTATIONS

H. W. FAIRBAIRN AND C. W. SHEPPARD

The notable lack of quantitative information regarding errors in many mineralogic computations has prompted the writers to construct a series of diagrams from which such information can be readily obtained. These include various determinative methods for density, refractive index, birefringence, and optic angle. Assuming a skilled operator and good working material, maximum values of the error in single observations are assigned to each procedure, so that the diagrams depict "worst" values of error rather than "probable" error as determined by standard methods from a series of observations. Comparison of the various procedures is based on this maximum expected error.

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* Published by permission of the Director, U. S. Geological Survey.

STRIKING CASE OF PEGMATITIC ALBITIZATION

D. JEROME FISHER

At the High Climb pegmatite (six miles north of Custer, S. Dak.), vein-like masses of quartz-cleavelandite rock invade large crystals of microcline microperthite. Specimens of the latter from the contact show the development of chess-board albite by replacement for a distance of an inch or two. This is well brought out in a 3 by 3½-inch thin-section made from this material. Kodachromes of most of the whole thin-section, and also of selected portions of it, will be shown and described. Some of these views (in black and white) appear in Report of Investigations No. 50 (1945) of the South Dakota Geological Survey. In addition this large thin section carries many tiny poikilitic cleavelandites, generally as anhedral individuals or pairs. In other thin sections these are aggregated into vein-like masses. The evidence showing these formed early in the paragenetic sequence will be summarized. A kodachrome of a giant beryl crystal at the Ingersoll Mine near Keystone will also be presented.

BASTINITE, A NEW PEGMATITE PHOSPHATE

D. JEROME FISHER

Bastinite occurs as tiny triclinic crystals of modified parallelopipedal habit, very rarely appearing along fractured surfaces of lithiophilite of the Custer Mountain Lode, two miles east of Custer, South Dakota It is transparent, nearly colorless, brittle, without cleavage, H. 4, F. 1. It is non-pleochroic, with $\alpha=1.649$, $\beta=1.655$, and $\gamma=1.658$; $(-)2V=73°$. It is a phosphate of lithium, with iron and manganese; it is readily soluble in dilute mineral acids. Along the lithiophilite fractures are found lilypad-shaped films of sicklerite or its alteration products; the bastinite occurs as drusy aggregates fringing but not overlapping these, and is thought to be of very late hydrothermal origin. The name is after Edson S. Bastin, a long-time colleague of the writer, who made significant contributions to the study of pegmatites.

PROJECTIONS AND ZONES

D. JEROME FISHER

The quadruple primitive gnomonogram (QPG) is the quadrilateral in the gnomonic projection joining the face poles $\{111\}$ (except in the hexagonal); a similar figure in the stereographic projection is the quadruple primitive stereogram (QPS). The quadruple primitive enthygram (QPE) is the quadrilateral in the gnomonic projection plane joining the zone-poles $\langle 111\rangle$ (except in the hexagonal); the corresponding figure in the stereographic constitutes the quadruple primitive cyclogram (QPC). Each of these figures may be divided into four portions by "bisectors," lines joining the "middles" of their sides. The QPG and QPE are reciprocal quadrilaterals; they coincide only in the isometric. Relations among these various figures, as well as their uses in crystallography (with examples) are pointed out.

THE OCCURRENCE OF TUNGSTEN AND VANADIUM IN MANGANESE OXIDE ORES AND MINERALS*

MICHAEL FLEISCHER, S. K. NEUSCHEL, AND J. M. AXELROD

The occurrence of tungsten in manganese oxide ores was first noted by Penrose in 1890 and since has been discussed by several authors. Vanadium has been reported in four analyses of manganese oxides. New analyses in the Chemical Laboratory of the Federal Geological Survey have shown that these elements occur commonly in manganese oxide ores, especially in those from the southwestern United States. Over fifty new occurrences have been noted and many more will doubtless be found by systematic chemical testing.

In some deposits, the tungsten and vanadium content of the ore varies directly with the manganese content, indicating that the tungsten and vanadium are in the manganese oxide mineral. This is not true of a few deposits, including that at Golconda, Nevada. *X*-ray study and chemical analysis show that tungsten and vanadium occur most frequently in manganese oxides that contain barium. Over three-fourths of the tungsten-bearing samples studied are the barium manganate psilomelane. Over two-thirds of the vanadium-bearing samples studied are either psilomelane or hollandite.

No generalizations can yet be made as to the origin of the tungsten-bearing and vanadium-bearing manganese oxide ores. Many are of hydrothermal origin, but some appear to be secondary.

MINERALOGY OF CONCRETIONS FROM PITTSBURGH COAL SEAM, MONONGALIA COUNTY, WEST VIRGINIA

WILDER D. FOSTER AND FLORENCE L. FEICHT

Four concretions were found in the Pittsburgh coal bed at Pursglove, Monongalia County, West Virginia, and were collected for study to get a better understanding of acid formation in the mine. Three of the concretions were mainly pyrite and the fourth was mainly dolomite. Associated with one or more of these concretions were these minerals: analcite, brammallite, calcite, dolomite, kaolinite, melanterite, pyrite, and an unknown mineral. The Pittsburgh coal bed is of Pennsylvanian age, and the base of the Monongahela formation. Analcite has been found in sedimentary rocks, identified as a constituent of boiler scale, and synthesized under hydrothermal conditions. In all cases it has been formed under alkaline conditions; it is decomposed by acid. It is supposed that alkaline solutions containing sodium reacted with a clay to form the analcite. Acids in the coal bed could have been neutralized by ground water passing through a limestone bed a few feet above the coal.

Analcite was synthesized at atmospheric pressure and 90°C. by allowing NaOH solution to react on kaolinite for 29 days. Only a small amount was formed; most was unidentified material.

MINERAL SHAPE FACTORS FOR USE IN QUANTITATIVE MICROSCOPIC ANALYSIS

WILFRID R. FOSTER

The problem of correcting for grain shape differences among the various constituents of granular mineral mixtures has been approached in a somewhat different manner than heretofore. Shape factors have been derived directly from the following equation relating grain volume to the projected grain area as viewed under the microscope: $V = KA\sqrt{A}$. A simple and rapid method for deriving the shape-factor of any desired mineral has been developed. It has been found that such factors, when used in the analysis of standard mineral mixtures are capable of yielding accurate results.

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SECONDARY DAUPHINÉ TWINNING IN QUARTZ PRODUCED BY SAWING

CLIFFORD FRONDEL

Instances are described in which Dauphiné twinning has been formed artifically in quartz by sawing. The secondary twinning occurs as a very thin surface layer, usually on one side of the saw cut only, and seems to have been produced by frictional heat developed at the cutting edge of the saw blade. The twinning often is restricted to particular growth zones in the quartz. The tendency to twin is related to the tendency of the quartz to become smoky in color when irradiated with *x*-rays, easily twinned quartz being relatively little affected, and not to the original smoky color. The frequency-thickness constant, K, of easily twinned quartz is relatively low; and that of natural deep smoky quartz increases when the color is baked out. These observations and the apparently significant variations reported in the density, cell dimensions, rotatory power and indices of refraction may stem from a defect structure in the substance.

The boundaries of some natural Dauphiné twins in quartz correspond with natural smoky color zones. In these specimens the original boundary of the twin is returned more or less exactly when the crystals are reinverted at 573°C., and a differential smoky coloration opposite to that existing initially is effected across the original twin boundary by radiation. Brazil and natural Dauphiné twins of colorless quartz sometimes also are differentially colored by radiation.

FREQUENCY OF TWINNING IN QUARTZ CRYSTALS*

H. R. GAULT

More than 900 singly and doubly terminated quartz (low) crystals from five different geologic and geographic locations were etched with HF acid to show external twin boundaries. Most observations were made on the terminal faces.

In addition to untwinned crystals, twins of the Dauphiné, Brazil, combined Dauphiné-Brazil, and Liebisch types were observed.

The proportions of untwinned and twinned crystals and of twin types vary considerably from locality to locality. At each locality untwinned and Dauphiné crystals are about equally divided between right- and left-handed quartz. Any crystal twinned according to (1) the Brazil law, (2) the Dauphiné-Brazil laws combined, or (3) the Liebisch law shows both right and left quartz but one or the other generally predominates. The number of crystals with right quartz predominating is about equal to the number with left quartz predominating.

At least 100 crystals from a given locality should be examined to determine the frequency of twinning.

Further work is in progress to determine if in some cases twin boundaries are confined to the interior of a crystal.

OCCURRENCE OF MICA-BEARING PEGMATITES IN THE SOUTHEASTERN STATES*

W. R. GRIFFITTS, E. WM. HEINRICH, R. H. JAHNS, J. C. OLSON,
AND J. M. PARKER III

Mica-bearing pegmatite has been mined extensively in the southeastern United States, particularly in eleven well-defined districts. The Spruce Pine and Franklin-Sylva districts in the Blue Ridge province of North Carolina, and the Alabama and eastern Virginia Piedmont areas are geologically representative of the entire group. Nearly all the deposits occur in mica and hornblende gneisses and schists, and appear to be genetically related to near-by leucocratic intrusive rocks that range in composition from quartz monzonite to quartz diorite. About four-fifths of the pegmatites in the Alabama and Spruce Pine districts are sills or concordant tongues and lenses; most of the others in the Spruce Pine district are dikes in coarse-grained granodiorite and quartz diorite. In contrast, most of the Franklin-Sylva and Virginia pegmatites are steeply dipping dikes, discordant lenses, and more complex bodies.

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Plagioclase, quartz, microcline, and muscovite are the dominant pegmatite constituents. Biotite, garnet, and apatite are common accessories; beryl, tourmaline, and sulfide minerals are sparse but widespread in some districts; and lithium, tantalum-columbium, tin, and uranium minerals are rare except in a few Virginia deposits. Nearly all the pegmatite bodies appear to have formed from the walls inward, perhaps by crystallization from liquid. Definite evidence for or against their development by large-scale, complete or nearly complete replacement of pre-existing pegmatite is almost lacking. Although some of the minerals and mineral aggregates plainly were formed by replacement, only a small proportion of material can be assigned such an origin with assurance.

HIGH TEMPERATURE THERMAL EFFECTS OF CLAYS AND RELATED MATERIALS*

R. E. GRIM AND W. F. BRADLEY

A selected series of clay minerals and related silicates are examined by thermal, optical, and x-ray diffraction methods with a view toward establishing the significance of the various observed thermal effects. The heating range for the thermal curves is extended to 1300°C., and the study of specimens so fired is supplemented by the examination of the various materials after firing to several intermediate temperatures.

Detailed hypotheses are presented for the mechanisms of several of the structural changes observed as new phases are developed and the influence of types of structures upon the nature and rapidity of such changes is discussed.

DICKITE AND CHROMIUM SILICATE IN THE IRON ORES OF THE MARQUETTE AND GOGEBIC RANGES, MICHIGAN

JOHN W. GRUNER

Dickite has been found in the Mather and Cambria Jackson mines on the Marquette Range. It is a massive variety cementing soft earthy hematite breccia. It is white and has silky luster. Under the microscope it is fibrous. Its optical constants agree with published ones. It gives a very fine x-ray pattern.

Some earthy hematite in the Mather Mine contains a waxy, emerald green mineral which gives a poor x-ray pattern of a mica-like substance. It has parallel extinction and fairly high birefringence. Its indices are similar to muscovite. It contains at least 12.7% Cr_2O_3. Similar chromium-bearing silicates, though more like kaolinite and chlorite, have been found in the Sunday Lake and Montreal mines on the Gogebic range. At Montreal they occur in the ore. At Sunday Lake they are associated with the "footwall slate."

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ISOSTRUCTURAL RELATIONSHIP OF $AlPO_4$ AND $SiSiO_4$

JOHN W. GRUNER

Huttenlocher (1935) has shown that the structure of $AlPO_4$ and α quartz are very closely related. Their optical properties, densities and hardnesses are also surprisingly similar. Their unit cells are almost identical in size except for a doubling of the *c* axis. Struntz has shown (1942) that berlinite found in Sweden and listed in mineralogy texts as $AlPO_4 \cdot H_2O$ is identical with $AlPO_4$, possessing the quartz structure. The author has confirmed the experiments of Huttenlocher and has been able to grow needles of $AlPO_4$ on sand grains of quartz in oriented patterns, also on some faces of quartz crystals.

In other experiments with $AlPO_4$ in bombs between temperatures of 150–250°C. microscopic snowflake-like crystals of α tridymite structure were formed. These have indices close to 1.46. Their density is in neighborhod of 2.30. Wavellite and variscite when heated in a crucible to low redness for a short time also assume the structure of tridymite. Under certain conditions in bomb experiments between 300° and 480°C. $AlPO_4$ forms cristobalite structures. The very small almost microscopic aggregates have indices of $1.465 \pm .002$ and a density of 2.28–2.29. The $AlPO_4$ α quartz structure (berlinite) will slowly invert to the cristobalite structure at 850° to 1000°C. Amorphous chemical precipitates of $AlPO_4$ when heated to 675°C., or above, give the cristobalite *x*-ray pattern. The writer does not believe that a β tridymite structure of $AlPO_4$ exists.

CHROMITE DEPOSITS OF CAMAGUEY PROVINCE, CUBA*

PHILIP W. GUILD AND DELOS E. FLINT

The chromite-bearing ultramafic complex near Camaguey, Cuba, mapped as a part of the program of mineral investigations of the Federal Geological Survey, consists chiefly of serpentinized peridotite (harzburgite) and dunite, with minor amounts of the feldspathic rocks gabbro, troctolite, and anorthosite. This complex and the overlying Cretaceous tuffs and limestones were severely deformed in an orogeny which culminated in extensive thrust faulting, probably in late middle Eocene time. The sedimentary rocks now occur in two synclinal arcs extending across the district parallel to the trace of the thrust. The feldspathic rocks of the complex flank the tuffs along the limbs of the syncline, indicating that they were concentrated in the upper part of the complex.

The chromite occurs as tabular or lenticular bodies of massive, coarse-grained, or occasionally fine-grained disseminated ore. Virtually all the known deposits are near the base of the feldspathic zone, but with an irregular lateral distribution which distinguishes them from the layered chromitites of the Bushveld-Stillwater type. Two possible modes of origin are discussed: (1) segregation of the deposits near the feldspar-peridotite boundary after emplacement of the magma through some process of gravity separation and magmatic flow; (2) differentiation of chromite at great depth before intrusion and transportation of the ore bodies as solid masses to their present position. The grouping into clusters, as though near feeders, and the massive texture and sharp contacts of many of the deposits suggest that the latter hypothesis is more probable.

BERYLLIUM AND TANTALUM PEGMATITES OF COLORADO*

JOHN B. HANLEY

The beryllium and tantalum minerals of Colorado pegmatites are found together in the same structural units of the pegmatites, but in a variety of mineralogical associations. Beryllium-tantalum pegmatites are particularly abundant in Larimer, Fremont, and Gunnison counties, although a few occur in other parts of the state.

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During detailed mapping in 1942–44 by geologists of the U. S. Geological Survey, 51 individual pegmatites containing concentrations of beryl, chrysoberyl, columbite-tantalite, or microlite were studied. The largest concentrations of these minerals are in the intermediate zones of the pegmatites, although minor concentrations occur in all zones.

Beryl, the most common beryllium mineral, occurs in subhedral to euhedral crystals with a high beryllia content. It is associated chiefly with albite, muscovite, and quartz, as at the Devil's Hole, Mica Lode, and Hyatt Ranch pegmatites, or with lepidolite, cleavelandite, and quartz, as at the Brown Derby and the Meyers' mine pegmatites. Chrysoberyl appears to be most abundant at the Wisdom Ranch pegmatite, but is not very abundant in any pegmatite.

Columbite-tantalite is the most widespread tantalum mineral. Commonly it is associated with beryl, albite, muscovite, and quartz, and occurs particularly in the intermediate zone, for example at the Devil's Hole, Bigger, and Meyers' Ranch pegmatites. Microlite is common in the pegmatites of the Quartz Creek District, where it occurs with beryl, lepidolite, cleavelandite, topaz, and quartz. The Brown Derby and White Spar No. 1 pegmatites show examples of this association.

LITHIA PEGMATITES OF THE BROWN DERBY MINE, GUNNISON COUNTY, COLORADO*

JOHN B. HANLEY

Three parallel, elongate lithia pegmatites crop out at the Brown Derby mine in sec. 3, T. 49 N, R. 3 E., Gunnison County, about 17 miles by airline due east of the town of Gunnison, Colorado. These pegmatites were studied and mapped at various times in 1942, 1943, and 1944 by geologists of the U. S. Geological Survey.

The three pegmatite bodies, designated the No. 1, No. 2, and No. 3 dikes, strike N. 56° E., across the schistosity of the meta-diorite wall rock, and have a general dip of 30° to 35° SE. The No. 1 dike has an exposed length of about 900 feet and a maximum thickness of 20 feet. The other dikes are not as long but are as thick or thicker. The general plunge of the No. 1 dike probably is 22° S. 28° E., and so far as is known the ore concentrations beneath structural rolls in the hanging-wall contact are parallel to this plunge.

Well-defined mineralogical and textural zones, recognized by contrasts in kinds and proportions of component minerals, are characteristic of these pegmatites. The zones are nearly parallel to the walls, and in general conform to the structure of the pegmatite bodies.

Lepidolite and microlite are the economically important minerals. These commonly are associated with quartz, cleavelandite, topaz, and beryl. Lithia, tourmaline, microcline, muscovite, zinnwaldite, biotite, fluorite, gahnite, betafite, garnet, columbite, and monazite also occur in these pegmatites, but in different zones.

COMPOSITE PEGMATITES OF THE FRANKLIN-SYLVA MICA DISTRICT, NORTH CAROLINA*

E. WM. HEINRICH

Granite occurs in eleven mica-bearing pegmatites in the Franklin-Sylva district, North Carolina. In some it is flanked by later pegmatite, but in others it appears to have been intruded along the central part of the pegmatite during the final stages of pegmatite consolidation. Granite also occurs as inclusions and as narrow dikes that cut across the mica deposits. Both rocks appear to be related in origin to the large masses of Whiteside granite that lie along the southeast side of the mica district.

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BISMUTH MINERALS IN COLORADO AND NEW MEXICO PEGMATITES*

E. WM. HEINRICH

Bismuth carbonates occur in pegmatites in Fremont, Park, and Gunnison counties, Colorado, and in the Petaca district, Rio Arriba County, New Mexico. In many deposits they appear to be alteration products of late-stage fracture-filling bismuth sulfides or sulfosalts. The most common species is bismutite (Bi_2CO_5), but beyerite, a carbonate of bismuth and calcium, was identified by *x*-ray powder methods from two localities.

PORTABLE DIFFERENTIAL THERMAL ANALYSIS UNIT FOR BAUXITE EXPLORATION†

STERLING B. HENDRICKS, SAMUEL S. GOLDICH, AND REUBEN A. NELSON

A small differential thermal analysis unit that embodies the fundamental features of larger laboratory models is designed for field exploration for bauxite and related materials. The apparatus, requiring only a source of electrical power, combines portability with ease of operation and rapid analysis. The portable unit is suitable for quantitative work and has been successfully applied in bauxite exploration on the island of Hispaniola.

THE WHITE ARSENIDES OF NICKEL AND COBALT OCCURRING AT FRANKLIN, N. J.

RALPH J. HOLMES

Koenig, in 1889, described a white arsenide of nickel and cobalt from Franklin, noting that although isometric crystals were present, the material was "generally prismatic." Nevertheless, he regarded the massive prismatic material and the encrusting isometric crystals as a single homogeneous mineral, chloanthite.

Several specimens agreeing with Koenig's description were studied. *X*-ray and microscopic data show this material to be a complex mineral instead of the single isometric arsenide, as assumed by Koenig. An isometric arsenide, skutterudite, containing both cobalt and nickel is present but is a minor constituent encrusting large nodular masses of rammelsbergite intergrown with pararammelsbergite (Koenig's prismatic material). The orthorhombic nickel arsenides are in part rimmed with gersdorffite.

Data on the properties and relations of the several minerals are presented. The study shows that the orthorhombic minerals rammelsbergite and pararammelsbergite are the principal white arsenides of cobalt and nickel in the specimens observed. It confirms the presence of an isometric arsenide, skutterudite, but shows it to be a minor component. Pararammelsbergite and gersdorffite, not previously reported, are added to the ever growing list of species found at this locality. The presence of rammelsbergite has already been pointed out by the writer. The recognition of skutterudite does not add to the total list of species since it merely replaces Koenig's term chloanthite for the isometric arsenide.

THE PREPARATION AND STANDARDIZATION OF DIAMOND POWDERS

HERBERT INSLEY AND B. L. STEIERMAN

A brief account is given of the methods used and the results obtained in a study of grain size separation of diamond dusts with a view to recommending an adequate and practical apparatus for separating size fractions of diamond dusts commercially.

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BAUXITE "EGGS"

PAUL F. KERR

More or less spheroidal aggregates of bauxite are found at Poços de Caldas, Brazil, and in Surinam. These egg-like shapes are believed produced by gel-shrinkage at a final stage in lateritization. The forms are at times hollow or may be filled with white gibbsite powder and exceed by several inches the usual diameters of pisolites. At Poços de Caldas joint blocks in phonolite are considered to have altered in situ, first to laterite, subsequently to bauxite "eggs." In Surinam relict outlines of earlier rock are retained in the spheroids. The interpretation of the significance of the forms is based upon field observations at Poços de Caldas and laboratory study of both sets of materials. Microscopic, *x*-ray, and chemical methods of investigation have been employed.

BONDED DIAMOND WHEEL APPLICATIONS

A. A. KLEIN AND C. R. VAN RIPER

The use of bonded diamond wheels is briefly considered, the fields of application being: precision and off-hand grinding of cemented carbides and the grinding of quartz, sapphire, ophthalmic lenses, plate glass, glass prisms, granite and marble.

OCCURRENCE AND DISTRIBUTION OF IRON MINERALS IN PENNSYLVANIA FIRE CLAYS

EARL LEATHAM

Millions of tons of flint fire clay occurring in Clearfield and adjoining countries of Pennsylvania are of no industrial value because of the high content of iron minerals. The amount of iron minerals expressed as Fe_2O_3 usually varies between 8 and 15 per cent. A study of the occurrence and distribution of the iron minerals was made to evaluate the possibility of removing the iron by beneficiation.

The contact print method, as described by Gregorie Gutzeit, was used because it was simple and rapid. Gelatin-coated white paper treated with the proper reagents was pressed against a polished surface of clay. A colored iron compound was formed opposite each iron mineral.

It was found that most of the iron occurred as siderite with minor amounts of pyrite or marcasite. There was marked variation in the size of the siderite crystals from different parts of the area. In one relatively small area, the siderite crystals averaged 0.5 millimeters in diameter. Probably this clay could be beneficiated. Throughout the greater part of the area, the diameter of the siderite crystals averaged less than 0.02 millimeters. It is doubtful if such clay could be beneficiated commercially.

OCCURRENCE OF BROMINE IN CARNALLITE AND SYLVITE FROM UTAH AND NEW MEXICO

MARIE LOUISE LINDBERG

Both carnallite and sylvite from Eddy County, New Mexico, contain 0.1 per cent of bromine. The bromine content of these minerals from Grand County, Utah, is three times as great. No bromine was detected in halite, polyhalite, langbeinite, or anhydrite from New Mexico. Iodine was not detected in any of these minerals.

On the basis of the bromine content of the sylvite from New Mexico, it is calculated that 7,000 tons of bromine were present in potash salts mined from the Permian basin during the period 1931 to 1945.

CONSTRUCTION AND STUDY OF FLOW STRUCTURE MODELS FROM FIELD DATA

KURT E. LOWE

Investigators of intrusive rocks on a regional or reconnaissance scale frequently lack both time and facilities for petrofabric study with the universal stage. Limited or inadequate exposures may add to the difficulty of ascertaining flow structures in the field. The construction of transparent models based on field measurements has proven helpful in the study of the Storm King granite of the Hudson Highlands and is suggested as a useful laboratory and training device.

Field measurements are made on 8 to 10 exposure surfaces of varying orientation including strike and dip of surface, pitch of lineation, mineral pattern (field sketches), fracture systems, etc. A plan of the model is laid out on graph paper, starting with a top horizontal plane bounded by lines of intersection (strike lines) with the measured inclined surfaces suitably grouped by parallel translation. For a given model height, auxiliary scales are prepared for the vertical projection (*A*) and true length (*B*) of planes dipping 0° to 90°. The ground plan is drawn (using *A*) and the cut-out pattern constructed (using *B*) by rotating each surface into the top plane about its top edge. An ink tracing is made on transparent cellulose acetate (.015″ thick) and mineral lineation, distribution pattern fracture traces, etc. are added from field notes. The acetate is cut, folded and bonded to form the model.

Orientation of the model on a compass rose provides a means of determining flow structures with a degree of accuracy within limits of error inherent in the original field measurements.

A GRAPHIC SOLUTION FOR CERTAIN LINEATION PROBLEMS

KURT E. LOWE

The coordinates of linear flow structure can be determined graphically from field measurements provided it is not complicated by the presence of flow layers and the linear elements are minerals possessing prismatic habit with essentially equi-dimensional cross-section (e.g. quartz, hornblende, pyroxene).

The method is based on a simple geometric relationship involving an ideal, cylindrical linear element cut by a plane (=exposure surface). The long axis of the cutting-ellipse (=direction of surface lineation) and the cylinder axis (=orientation of linear structure) lie in a plane normal to the cutting plane. Two such normal planes derived from two different cutting planes intersect in the sought axis of the cylinder.

Strike and dip of an exposure surface and pitch of its mineral lineation are measured in the field and plotted on a Wulff net in the conventional manner. By rotating the net a plane (*N*) is found which contains both the line of lineation and the plane-normal to the surface. This procedure is repeated for at least 8 surfaces of different orientation. In the ideal case all resulting *N*-planes intersect in a single line. Actually multiple answers for the linear orientation result, depending on the approach of field conditions to the theoretical ideal. The problem is solved by statistical determination of the arithmetical median from all the possible bearings and plunges arranged in numerical order.

Encouraging results have been obtained by application of this method to the hornblende orientation in the Storm King granite of the Hudson Highlands.

AN UNRECORDED ALTERED PERIDOTITE DIKE IN SYRACUSE, NEW YORK

JAMES E. MAYNARD AND LOUIS W. PLOGER

The rock investigated occurs near the intersection of Salt Springs Road and East Genesee Street, Syracuse, New York. Where exposed, it intrudes the nearly horizontal Camillus Formation as a dike-like mass approximately 51 inches wide. The material, largely altered, consists of small grains, small composite fragments and greenish brown, friable, masses that occasionally are porphyritic in appearance. Geologic, petrographic and chemical studies show that this material has resulted from the alteration of a rock of the peridotite family.

The altered peridotite consists, primarily, of serpentine, pyroxene (probably hypersthene), vermiculite, iron oxides and perofskite. In addition there are small quantities of olivine, hypersthene, phlogopite, apatite, andesine, quartz and carbonates. Including the secondary minerals with the minerals from which they were derived, preliminary investigation suggests that hypersthene, olivine and phlogopite are the essential minerals of the unaltered rock. According to Johannsen's classification, therefore, the unaltered rock may be tentatively classified as a hypersthene-phlogopite peridotite (417).

PETROLOGY OF THE NEPHELINE AND CORUNDUM-BEARING ROCKS OF SOUTHEASTERN ONTARIO

LOUIS MOYD

Southeastern Ontario is noted for its great variety of unusual rocks and rare minerals. However, there appears to have been no concerted effort to develop a clear and logical picture of the genetic relations of such diverse types as the foliated nepheline and corundum-bearing rocks, rare element-rich pegmatites, calcite-rich "vein-dikes," dark gneisses, and marbles.

After several years in the field, a distinct pattern became apparent to the author. Field evidence indicates that most of the nepheline and corundum-bearing rocks, among others, are migmatites, formed from pre-existing rocks of the Grenville Series. Since many other regions have been invaded by granitic magmas without development of similar migmatites, some factor peculiar to this region must be considered. The author believes that paucity of silicious rocks and superabundance of marbles in the Grenville provide the key.

The genetic sequence would be first, the intrusion of granitic masses into the silica-poor Grenville terrain. These for the most part would crystallize normally, giving rise to usual silicious pegmatites and emanations and granitizing the gneissic country rocks. However, some of the magma would react with the dolomitic marbles, releasing emanations rich in carbon dioxide. These emanations, while traversing the silica-poor country rocks would lose much of their silica, forming granitic and syenitic migmatites and finally, impoverished in silica, would form more unusual migmatites. These mineralizer-rich emanations could convert the high lime feldspars of the dark gneisses to alkali feldspars, releasing alumina to form nepheline or corundum, and lime to produce the ubiquitous pockets of calcite, accompanied by fluorite, apatite, sphene, scapolite, and other minerals containing lime in combination with mineralizers.

STUDIES OF MINERAL SULPHO-SALTS: XI—WITTICHENITE (KLAPROTHITE)

E. W. NUFFIELD

Wittichenite and klaprothite were undistinguished under the name Kupferwismutherz, later wittichenite, until Petersen (1868–1869) restricted wittichenite to the mineral with the composition $3Cu_2S \cdot Bi_2S_3$, and proposed klaprothite for a mineral resembling emplectite ($Cu_2S \cdot Bi_2S_3$) which gave a composition near $3Cu_2S \cdot 2Bi_2S_3$. *X*-ray examination of numerous specimens labelled wittichenite or klaprothite from the Wittichen mines, Baden, gave only wittichenite and emplectite. The wittichenite pattern is identical with that given by the homogeneous fusion product $3Cu_2S \cdot Bi_2S_3$. A crystal, part of which gave the wittichenite pattern, yielded the orthorhombic unit cell with $a = 7.66$, $b = 10.31$, $c = 6.69$ kX; space-group $P2_12_12_1$; contents $2[3Cu_2S \cdot Bi_2S_3]$. Many published observations on "klaprothite" evidently refer to wittichenite and it appears that Petersen's analyzed "klaprothite" was a mixture of wittichenite and emplectite.

NOTES ON THE STRUCTURE OF DELAFOSSITE

A. PABST

In a previous report it was shown that delafossite probably has the same structure as artificial $CuFeO_2$. The density corresponding to this structure, 5.52, agrees closely with the best measured value, 5.41, reported in the 7th edition of Dana's System of Mineralogy.

Published accounts of powder patterns of delafossite cannot be fully reconciled with the requirements of the structure. It is recommended that even patterns intended only for identification should be indexed and checked against the literature.

The valence state of copper and iron in delafossite has been considered by Rogers. From a consideration of the intensities of powder diffraction lines it is possible to choose rather closely the single parameter of the delafossite structure. This determines the interionic distances Cu–O and Fe–O. From these one can draw conclusions as to the valence state of the copper and iron by comparison with corresponding interionic distances in other compounds of these metals. Such a comparison leads to the conclusion that delafossite is cuprous metaferrite, $Cu'Fe'''O_2$, as surmised by Rogers.

It is shown that it is a matter of indifference whether ionic or atomic f values are used in making the necessary intensity calculations since the calculated intensities vary much more with moderate changes in interionic distance than with change in the scattering power of the ions.

Incidentally it is also shown that certain ambiguities still remain in the stucture of delafossite. These cannot be relieved by the study of powder patterns alone which do not allow the discrimination of a parameter x from $\frac{1}{2}-x$.

CONTACT METAMORPHIC DEPOSITS OF CASSITERITE IN CALIFORNIA*

LINCOLN R. PAGE

Small quantities of cassiterite have been produced at the Evening Star mine in the Cima district, San Bernardino County, and from the Meeks mine in the Gorman district, Kern County, California. These deposits are of the contact metamorphic type and were investigated by the Geological Survey in 1940–1944.

The Evening Star deposit is in dolomite and dolomitic marbles near an intrusive body of quartz monzonite. Cassiterite occurs with scheelite, chalcopyrite, sphalerite, pyrite, and magnetite as disseminated grains, euhedral crystals, and massisve aggregates in tremolite-serpentine-calcite rock. Near the surface hematite, limonite, malachite, chrysocolla, melaconite, calamine, and other secondary zinc minerals are common. Talc is associated with brecciated cassiterite along shear zones that cut the ore.

The irregular, lenticular ore bodies of the Evening Star deposit were formed by replacement of favorable beds along and outward from a mineralized zone which is 120 feet long and up to 20 feet wide.

In the Gorman district cassiterite has been identified in six small, irregular bodies of iron-rich tactite and limonitic gossan that occur in recrystallized limestone at the margin of a granite intrusive. The primary ore contains cassiterite, scheelite, powellite, pyrite, chalcopyrite, arsenopyrite, molybdenite, magnetite, epidote, tourmaline, ludwigite, amphibole, garnet, phlogopite, calcite, and quartz, though not all of these minerals occur in each deposit. The gossanin deposits such as the Neeke also contain malachite, chrysocolla, jarosite, gypsum, chalcedony, opal, cuprite, native copper, and clay minerals.

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STRUCTURAL AND MINERALOGICAL CHARACTERISTICS OF SOUTH DAKOTA PEGMATITES*

LINCOLN R. PAGE

Detailed structural and economic investigations of over one hundred and forty South Dakota pegmatites by members of the Geological Survey in 1939–1945 have shown that many of the pegmatites exhibit similar structural and mineralogical characteristics. These characteristics have a direct bearing on the origin of pegmatites as well as on mining practice.

The important structural features of these pegmatites are: (1) external shape, (2) zoning, (3) gneissic banding, (4) orientation of minerals, and (5) internal cross structures. These structural features show a definite relation to the planar and linear structures of the wall rocks. In most pegmatites concentrations of minerals can be related to these structures.

The distribution of minerals in all the pegmatites studied seems to follow a general sequence related to the internal zoning, but the abundance of any particular mineral is controlled by the composition of the liquid from which the pegmatite formed and the history of crystallization. Variations in the chemical composition of plagioclase, beryl, and columbite-tantalite have been noted in different parts of a pegmatite and appear to be systematic when related to zonal structure. These variations in chemical composition may be accompanied by differences in physical form and color. The alteration of spodumene and the consequent decrease in lithia content appear to be related in part to its structural position in a pegmatite. Preliminary investigations suggest that perthite and microcline, as well as flat and "A" books of muscovite also have a preferred structural position.

CLINOCLASITE

CHARLES PALACHE AND L. G. BERRY

Clinoclasite, $Cu_3AsO_4(OH)_3$, is described from a new locality, Majuba Hill, Nevada, from Cornwall, and from Utah, with complete revision of its morphology. Monoclinic; prismatic—$P2_1/a$. $a:b:c=1.9109:1:1.1223$, $\beta=99°\ 22'$; $p_0:q_0:r_0=0.5873:1.1073:1$, $\mu=80°38'$; $a_0=12.36$, $b_0=6.45$, $c_0=7.23$Å, $\beta=99°30'$. Forms: $c(001)$, $a(100)$, $m(100)$, $g(\bar{2}01)$, $o(111)$, $q(\bar{1}11)$, and others less certain. The relations of the new elements to those hitherto used are explained. There are 4 units of the formula given above in the unit cell. An x-ray powder photograph is given.

GNOMONIC AND LINEAR HEPTAXIAL TWO-CIRCLE CALCULATION

A. L. PARSONS

Referring an hexagonal crystal to three sets of orthorhombic axes and taking $\phi_{(1-3)}$ and $\phi'_{(1-3)(=90°-\phi)}$ alternatively, gnomonic calculation yields the following:
$\cos\phi_{1-3}(\text{or }\phi'_{1-3})\cdot\tan\rho=$

$$\frac{k}{l}\cdot\frac{c}{a}:\frac{(h+2k)c}{l\sqrt{3}a}:\frac{(h+k)c}{la}:\frac{(2h+k)c}{l\sqrt{3}a}:\frac{h}{l}\cdot\frac{c}{a}:\frac{(h-k)c}{l\sqrt{3}a}.$$

Linear calculation yields the following:
$\tan(90°-\rho)/\cos\phi_{(1-3)}(\text{or }\phi'_{1-3})=$

$$\frac{l}{k}\cdot\frac{a}{c}:\frac{l}{h+2k}\cdot\frac{\sqrt{3}a}{c}:\frac{l}{h+k}\cdot\frac{a}{c}:\frac{l}{2h+k}\cdot\frac{\sqrt{3}a}{c}:\frac{l}{h}\cdot\frac{a}{c}:\frac{l}{h-k}\cdot\frac{\sqrt{3}a}{c}.$$

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The linear constants are a/c and $\sqrt{3}a/c$ and the reciprocal gnomonic polar constants are c/a and $c/\sqrt{3}a$, which, as they may be interchangeable, might be indicated as p_0 and π_0. The gnomonic polar representation of the facts shown in the linear projection of a face $(hk\bar{i}l)$ is a circle with tan ρ as diameter, which is used for the graphical determination of the polar constants. The linear projection is shown to be well adapted for use in two-circle calculation.

The calculation of the reciprocal (polar) constants depends on two sets of triangles (not polar) which are homopolar, with one common angle, and with the sides adjacent to this angle having reciprocal tangents.

MONTBRAYITE, A NEW GOLD TELLURIDE

M. A. PEACOCK AND R. M. THOMPSON

Triclinic; $a=12.08$, $b=13.43$, $c=10.78$ kX, $\alpha=104°30\frac{1}{2}'$, $\beta=97°34\frac{1}{2}'$, $\gamma=107°53\frac{1}{2}'$; cleavages $(1\bar{1}0)$, $(0\bar{1}1)$, $(1\bar{1}1)$; $(0\bar{1}1):(1\bar{1}1)=41°20'$, $(1\bar{1}1):1\bar{1}0)=46°45'$, $(1\bar{1}0):(0\bar{1}1)=69°31'$. Cleavages perfect but difficult. Fracture flat conchoidal. Very brittle. Hardness $2\frac{1}{2}$. Specific gravity 9.94. Luster metallic. Color tin-white to palest yellow. Polished sections white, moderately anisotropic, and homogeneous except for sparse ovoid inclusions of intergrown tellurbismuth and altaite. Analysis by Williams: Au 44.32, Te 49.80, Bi 2.81, Pb 1.61, Sb 0.90, Ag. 0.55, Fe trace; total 99.99. Cell content, after subtracting Bi as Bi_2Te_3, Pb as PbTe: $(Au, Sb, Ag)_{24}Te_{37}$ or nearly $12[Au_2Te_3]$. Occurs with gold, tellurbismuth, altaite, petzite, melonite, chalcopyrite, pyrite, sphalerite, chalcocite, and marcasite, in the Robb-Montbray mine, Montbray Township, Abitibi County, Quebec, Canada.

ON MELONITE FROM QUEBEC AND THE CRYSTAL STRUCTURE OF $NiTe_2$

M. A. PEACOCK AND R. M. THOMPSON

Melonite is associated with tellurides, sulfides, and gold, in rich ore from the Robb Montbray mines, Montbray Township, Abitibi County, Quebec. The mineral is structurally identical with $NiTe_2$ obtained by fusing the elements in vacuum, and x-ray powder photographs lead to the following structure (C6-type): hexagonal; space-group D_{3d}^3—$C\bar{3}m$ (ditrigonal scalenohedral class—$\bar{3}\ 2/m$); $a=3.835$, $c=5.255$ kX; cell content $NiTe_2$ giving the calculated specific gravity 7.73, measured 7.72 (Hillebrand); Ni at 000, 2Te at $\frac{1}{3}\ \frac{2}{3}z$, $\frac{2}{3}\ \frac{1}{3}\bar{z}$, with $z=0.250\pm0.005$. The distances Ni-Te $=2.58$. Te-Te $=3.44$ kX, agree with the sums of the appropriate predicted radii of Pauling. The previously published x-ray powder data for melonite include lines due to free gold. Melonite would be appropriately attached to the Molybdenite Group in systematic mineralogy.

APPLICATION OF THE HIGH VOLTAGE ARC TO THE CUTTING, SAWING, AND DRILLING OF DIAMONDS

CHAUNCEY G. PETERS

The method universally employed for cutting facets on diamonds has been to place the diamond in contact with a flat cast-iron lap charged with diamond powder and rotated at about 2000 revolutions per minute. For sawing, the edge of a thin metal disk charged with powder and rotated at high speed is brought in contact with the diamond. For drilling, the point of a hardened steel needle immersed in oil on diamond powder is vibrated against the diamond.

In the work described in this paper it was found that by applying a high voltage electric arc the rate of cutting is materially increased for all orientations of the diamond and rapid drilling is obtained without the aid of diamond powder.

EXPERIMENTS IN X-RAY IRRADIATION OF GEM STONES

F. H. POUGH AND T. H. ROGERS

The alteration of color in minerals as the result of irradiation by various rays of wavelengths shorter than those of visible light is a well-known phenomenon. However, previous experiments have been but casually mentioned in the literature and the possibility has not been recognized in many minerals because of the slowness with which the alteration takes place with ordinary radiators. The perfection by the Machlett Laboratories of a new and concentrated beam *x*-ray tube, with a beryllium window transparent to a wide spectrum suggested the possibility of performing some experiments which might lead to results observable in a matter of minutes, rather than hours or days. A large series of gem stones were tested, with the expected results in some cases and unanticipated changes in others. The most notable was the golden discoloration of white and pale yellow sapphires. None of the effects appear to be permanent, all of the colors reverting to the original in a short time, either with exposure to ordinary light or upon the application of a low degree of heat. The preliminary study suggests further steps which might be tried, and some possible economic applications.

THE CRYSTAL STRUCTURE OF α-SiC, Type V

LEWIS S. RAMSDELL

α-SiC, type V, originally discovered by Ott, has a rhombohedral unit cell, space group $R3m$, with $Z=17$. Referred to hexagonal axes, $a_0=3.073$A, $c_0=128.15$A, $Z=51$. Even with simplifying assumptions based on known types, the number of geometrically possible structures is large. However, by means of an extrapolation of what appears to be a definite series in the known types, a structure is predicted which agrees excellently with the observed data. This structure is as follows:

Hexagonal unit cell—

17 Si atoms at 000, 00 $2z$, 00 $6z$, 00 $8z$, 00 $12z$, 00 $14z$, 00 $18z$, 00 $21z$, 00 $24z$, 00 $27z$, 00 $30z$, 00 $33z$, 00 $37z$, 00 $39z$, 00 $43z$, 00 $45z$, 00 $49z$.

17 C atoms at 00 p, 00$2z+p$, 00 $6z+p$, 00 $8z+p$, 00 $12z+p$, 00 $14z+p$, 00 $18z+p$, 00 $21z+p$, 00 $24z+p$, 00 $27z+p$, 00 $30z+p$, 00 $33z+p$, 00 $37z+p$, 00 $39z+p$, 00 $43z+p$, 00 $45z+p$, 00 $49z+p$.

17 Si and 17 C at $\frac{2}{3}$, $\frac{1}{3}$, $\frac{1}{3}+$the above coordinates.

17 Si and 17 C at $\frac{1}{3}$, $\frac{2}{3}$, $\frac{2}{3}+$the above coordinates.

$$z=1/51;\ p=1/68.$$

Certain unifying principles covering all 7 known types of SiC are evident, and there seems to be no reason why additional types, both hexagonal and rhombohedral, may not be found.

BRAUNITE FROM SNOWMASS, PITKIN COUNTY, COLORADO

AUSTIN F. ROGERS

Braunite, tetragonal, with the probable composition $3Mn_2O_3 \cdot MnSiO_3$, a comparatively rare mineral in this country, is recorded from a new locality in Pitkin County, Colorado.

It is a massive, somewhat granular, black metallic mineral which shows in cavities the pseudo-octahedral crystals so characteristic of it.

Associated minerals are calcite, barite, manganophyll (manganian biotite), muscovite, quartz, microcline, and plagioclase, the three latter and probably the muscovite being detrital.

Calcite and barite are persistent minerals and thus give no clue to the type of deposit, but the presence of manganophyll points to a distinctly hydrothermal origin.

Attention is called to the importance of plane angles of crystals in the determination of minerals. Plane angles may be expressed as interzonal angles since edges of crystal faces are parallel to the corresponding zone-axes.

SAND FULGURITES WITH ENCLOSED LECHATELIERITE FROM RIVERSIDE COUNTY, CALIFORNIA

AUSTIN F. ROGERS

Sand fulgurites from the vicinity of Indio, Riverside County, California, produced by the incomplete fusion of sand derived from granodiorite contain fragments of lechatelierite formed by the more or less complete melting of some of the quartz grains. Some cristobalite is also present. The biotite grains are completely fused to a dark brown glass and feldspars are for the most part melted.

SAUCONITE—THE ZINC CLAY MINERAL

CLARENCE S. ROSS

Zinc clay materials, commonly called tallow clays, have been found to include hemimorphite-bearing clays, and zincian montmorillonite; but the characteristic member of the group is a definite zinc mineral analogous to saponite. Comparison of samples from three regions with type sauconite from Friedensville, Pennsylvania, shows that all are similar. Therefore the validity of the name sauconite for a definite zinc clay mineral has been verified.

DEVELOPMENTS AND TRENDS IN THE USE OF INDUSTRIAL DIAMONDS

CHESTER B. SLAWSON

Only in the last decade has an appreciable percentage of diamonds been used in industry except in the same form in which they were when mined. Research and technical development on industrial diamond tools were confined to methods of mounting the natural crystal and little or no attention was paid to processing the diamond. In the last ten years the application of scientific principles to the diamond itself has given rise to major developments in its industrial use. The crystallographic properties of the diamond applicable to its use industrially are reviewed.

MODERN ASPECTS OF GEOCHEMISTRY AND THEIR APPLICATION TO ECONOMIC GEOLOGY

TAISIA STADNICHENKO

Previous to the development of atomic physics and the knowledge of the laws of crystal chemistry, geochemistry depended mostly on descriptive mineralogy and the data derived from the chemical analyses of the rocks and minerals collected in the different parts of the lithosphere, hydrosphere, and atmosphere. The recognition of the reality of the concept of the atom-elements, systematic studies of their structures, and the laws of crystal chemistry gave a new impetus to the examination of the geochemical processes. While the frequency of occurrence of an element in the Cosmos depends on the structure of its atomic nucleus, the distribution, migration, accumulation and dispersion of the chemical elements and their compounds are determined by the electrons of the outer shells. The behavior of the atom-element in the crystal lattice is governed by the laws of geometric equilibrium and a crystal represents a complex electromagnetic field which is determined by the energy of the system.

The laws of atomic lattices explain such well known associations as: Cu, Co, Ni, and especially Cu and Fe; Zn, Fe, Mn; constant presence of Au in Ag; also less familiar series of Cd and In; Pt group with Fe, Cu, As and Mo; presence of Re in Pt ores and Mo compounds. The geochemical processes leading to the separation of Co from Ni and Fe is a complex function including such variables as: atomic weight, atomic number, coordination number, energy of the crystal lattices, and ionic radii.

In the last 20 years, particularly in Russia, the application of the new principles to the study of geochemical processes helped to formulate the important rules of geochemical associations, to forecast the distribution and accumulation of the various elements, and to suggest better means in solution of prospecting, mining, and technological problems.

PETROGRAPHIC COMPARISON OF PLIOCENE AND PLEISTOCENE VOLCANIC ASH FROM WESTERN KANSAS

ADA SWINEFORD AND JOHN C. FRYE

Lenticular, discontinuous deposits of volcanic ash occur in western Kansas in at least two stratigraphic positions within the Pliocene Ogallala formation and in one or more within the Pleistocene strata. The ash, which is extensively mined, attains a known maximum thickness of more than 20 feet. In an attempt to determine the feasibility of stratigraphic correlation by minor petrographic differences in the volcanic ash, a study was made of 30 samples from eight Pliocene localities and 24 samples from ten Pleistocene localities. Sieve analyses showed no consistent difference among the several samples even though a few zones of Pliocene ash were coarser than any sample of Pleistocene age. A color comparison of the fraction finer than 62 microns showed a consistent difference. Color differences are less pronounced in the coarser grades. A refractive index of about 1.501 is common to all Kansas samples studied except those from one Pliocene locality (R. I. ca. 1.506). The most prominent difference between the ash of the two ages is the presence of numerous elongated fluid inclusions in many shards in the Pleistocene samples. These are rare in the Pliocene ash, most of the particles of which are either clear or clouded with mineral and small equidimensional fluid inclusions. Chemical analyses of 27 samples show the Pliocene ash to be generally higher in iron. A sample of Pliocene ash from Hemphill County, Texas, showed most characteristics typical of Kansas Pliocene samples, but had a refractive index of about 1.496.

PRELIMINARY CHEMICAL CORRELATION OF CHROMITE WITH THE CONTAINING ROCKS*

T. P. THAYER

Chromite investigations of the Geological Survey since 1939 indicate that economic deposits of chromite rich in normative spinel ($(Mg, Fe)Al_2O_4$) occur in peridotites which are closely associated with gabbro; high-chrome chromites occur in feldspar-free peridotites; and chromites rich in both normative chromite ($(Mg, Fe)Cr_2O_4$) and magnetite (Fe_3O_4) are found in the pyroxene-rich stratiform complexes. Reaction of high-alumina chromite with diopsidic gabbro to form anorthite, olivine, and enstatite is described, and some probable equilibria between chromite and silicate minerals are discussed.

A plot of 60 complete analyses on a triangular prism of composition shows that chromites from different geologic provinces in the Western Hemisphere vary consistently and fall in overlapping, but distinct, fields. The chromites of the Caribbean Province, which occur in dunite and troctolite, have the general formula $Cr_{25-80}\ Al_{15-75}\ Mt_{1-5}\ (Mg_{65-75})$ and average about $Cr_{50}Al_{47}(Mg_{70})$. The chromites of the Pacific Coast, which occur in dunite and saxonite, average about $Cr_{70}Al_{24}(Mg_{60})$ in the range $Cr_{60-77}Al_{16-35}Mt_{3-12}(Mg_{45-75})$. The chromites of the Stillwater complex, like the stratiform Bushveld ores, occur in bronzite-rich rocks and are richer in iron; they average about $Cr_{60}Al_{32}(Mg_{52})$, and cover the range $Cr_{52-69}Al_{26-39}Mt_{5-10}(Mg_{45-61})$.

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RUTILE IN HARFORD COUNTY, MARYLAND

W. HAROLD TOMLINSON

Prospect pits have been sunk for rutile along the contact of a serpentine belt west of Pylesville in Harford County, Maryland. The ultra-basic rock has been injected into Wissahickon schist.

The formation is a chlorite rock with slightly schistose structure. Accessory minerals, magnetite, rutile, apatite, talc, biotite, ilmenite and zircon. The first six of these occur in pockets.

The rutile occurs as sagenite in groups through the chlorite rock and as stouter crystals in the pockets containing apatite. Pockets show 10% to 16% rutile by areal measurement in sections.

Origin of the deposit. There are in the vicinity large bodies of hypersthene gabbro which grade into pyroxenite. Apatite occurs freely in this gabbro and has been reported as forming 12% of the rock in certain pockets. Ilmenite has been reported as occurring in pockets in the pyroxenite. The author believes this rutile-bearing formation represents an ilmenite-bearing pyroxenite derived from the gabbro, which has undergone regional metamorphism. Specimens were found at the locality showing ilmenite partly altered to rutile.

MAGNESIUM MINERALIZATION IN THE CURRANT CREEK DISTRICT, NEVADA*

CHARLES J. VITALIANO

The Currant Creek District is in White Pine and Nye Counties, Nev., 35 miles southwest of Ely, Nev.

The host rock for the magnesium mineralization is a bedded calcareous tuff of late Miocene or early Pliocene age, overlain by quartz latite and underlain in the western part of the area by basaltic andesite and dacitic rock, and in the eastern part of the area by dacite. The thickness of the tuff is variable, but averages 300 feet. Unaltered tuff may contain as much as 80 per cent carbonate. All beds dip gently eastward from the summit of the Horse Range, but they are broken by a number of northeasterly-trending major faults and several minor faults of variable trend.

Magnesite replaces the calcareous tuffs and occurs as nodules, as veins or lenses, and as disseminated grains in masses of unaltered tuff. The associated minerals are dolomite, an unnamed magnesium silicate which may be a member of the serpentine group, calcite, and silica in the form of chalcedony, opal and quartz. The hard, dense, white nodules are distributed in zones, commonly a hundred or more feet in length. The lenses or veins may reach a length of 100 feet and a width of 12 feet, but are generally much smaller.

The silica minerals are late and transgress the others. Magnesite is earlier than the silica minerals. Its relation to the other carbonates is not always clear, but it is probably later than most of the dolomite.

The alteration is believed to have been due to ascending hot spring waters, rich in magnesia, that first formed the magnesium silicate and dolomite, and later replaced them by magnesite. Later solutions deposited various forms of silica which cut or replaced earlier minerals.

VECTOR HARDNESS IN DIAMOND TOOLS

HARRY WHITTAKER AND CHESTER B. SLAWSON

Diamonds varying from gem quality to opaque, irregularly shaped stones were used in abrasive tests against Al_2O_3 and SiC grinding wheels. It was found that, by weight, one part of diamond will abrade four million parts of the grinding wheel under the average conditions encountered in industrial practice. In the past, variations in the efficiency of the diamond, other than those attributable to structural failure, have been explained as due to the color, transparency or opaqueness, size, shape, or geographical origin of the diamond.

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These variations are shown to be due to the vector hardness of the diamond. Those directions that wear most rapidly develop a high lustrous polish often with an optical finish while the harder directions develop a fine matte finish. Points of the octahedron, either natural or lapped, are most suitable for dresser tools. The low esteem in which all forms of the diamond, other than the octahedron, are held in industry is chiefly due to the improper crystallographic orientation of the diamond in the tool. The harder directions have an average efficiency twice that of the average of the softer directions.

MINERAL OXIDATION

A. N. WINCHELL

Mineral oxidation is of two radically different kinds; one is the well-known oxidation during weathering which involves addition of oxygen and the other is the little known oxidation during anamorphism which involves elimination of hydrogen (but no addition of oxygen). The first destroys the primary mineral and forms new ones; the second merely modifies the primary mineral but does not destroy it. Examples of the second process are described and illustrated by diagrams.

HARDNESS VARIATIONS AND ORIENTATION IN DIAMOND

HORACE WINCHELL

The resistance of a crystal surface to abrasion varies with the orientation of the surface, and also with the direction of abrasion in it. Two independent coordinates (e.g., longitude and latitude) are necessary to specify the orientation of the surface tested, and a third coordinate (azimuth) is required to indicate the direction of abrasion. If desired, Miller indices (*hkl*) may be used to indicate the orientation of the surface, and zone symbols [*pqr*], to show the direction in it. Observations of hardness in selected directions on certain planes may be used to map out the systematic variations; remaining hardness values may then be estimated.

Experiments were conducted at the Hamilton Watch Company to measure the hardness variations in diamond. These measurements were made in terms of the number of pieces a certain production tool can finish satisfactorily before repolishing is needed. Some of the results are as follows:

Approximate Orientation		*Hardness*
Surface (*hkl*)	Direction [*pqr*]	Average
100	011	700*
210	$1\bar{2}0$	1600*
	$\bar{1}20$	2000*
110	$1\bar{1}0$	2700
	001	200
322	$4\bar{3}\bar{3}$	2000
	011	640
	$\bar{4}33$	10600
332	$1\bar{1}0$	3750
	$\bar{1}\bar{1}3$	11500
	$11\bar{3}$	250*

* Preliminary observation.

The maximum orientational hardness variation is at least 30:1, may be 150:1

LUMINESCENT PHENOMENA AS AIDES IN THE LOCALIZATION OF MINERALS IN POLISHED SECTIONS

HERMAN YAGODA

On exposure to ultraviolet light a considerable number of minerals become readily discernible as a result of fluorescence or phosphorescence. The resultant optical activity is usually associated with the presence of minor constituents. The fluorescent pattern can on occasion be utilized for the estimation of the trace element causing the activity, a notable example being the estimation of the molybdenum content of scheelites. An annular cold quartz ultraviolet illuminator is described which permits the microscopic examination of fluorescing minerals in polished sections. Photomicrographs up to 150 X magnification can be secured which are serviceable for aerometric analysis and for the study of mineral intergrowths.

The phosphorescence of minerals is best studied by direct contact printing avoiding the use of optical equipment. After irradiation the polished section is immediately placed on fast panchromatic film for about two minutes. On development a permanent record is secured showing the distribution of the phosphorescing constituents. This autoluminograph will often reveal constituents emitting radiations not visible to the eye but which activate the emulsion. By utilizing color-sensitive film a true color replica is recorded of the evanescent phosphorescence. Such patterns have proven useful in the study of the Franklin, N. J. mineral deposits. The autoluminographs localize the willemite (green), clinohedrite (orange), and hardystonite (purple); the accompanying calcite, franklinite and zincite are non-luminescent and are depicted as voids in the autoluminographic pattern.

The thermoluminescence of hackmanite and certain varieties of fluorite can be recorded photographically by warming the thin section on a hot stage beneath the camera.

These luminescent properties are being employed in the study of the distribution of dust particles in lung tissue, utilizing fluorescent hyalite opal and willemite as tracers for free and combined silica, respectively.

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1945 Adolf Pabst, Michael Fleischer, S. J. Shand, R. E. Grim

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1920 Chicago, Illinois
1921 Amherst, Massachusetts
1922 Ann Arbor, Michigan
1923 Washington, D. C.
1924 Ithaca, New York
1925 New Haven, Connecticut
1926 Madison, Wisconsin
1927 Cleveland, Ohio
1928 New York, N. Y.
1929 Washington, D. C.
1930 Toronto, Canada
1931 Tulsa, Oklahoma
1932 Cambridge, Massachusetts
1933 Chicago, Illinois
1934 Rochester, New York
1935 New York, N. Y.
1936 Cincinnati, Ohio
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1939 Minneapolis, Minnesota
1940 Austin, Texas
1941 Boston, Massachusetts
1942 No meeting held
1943 No meeting held
1944 No meeting held
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University Library, Stellenbosch, South Africa.
University College, The Librarian, Potchefstroom, Transvaal, South Africa.
University College of Swansea Library, Singleton Park, Swansea, England.
University of Arizona Library, Tucson, Arizona.
University of Arkansas, General Library, Fayetteville, Arkansas.
University of Berne, Mineralog, Petro. Institut, Berne, Switzerland.
University of British Columbia, Library, Vancouver, British Columbia, Canada.
University of Buffalo Library, 3425 Main Street, Buffalo, New York.
University of Calcutta, Secretary Geological Department, Senate House, Calcutta, India.
University of Calcutta Library, Darbhanga Buildings, Calcutta, India.
University of California Library, Berkeley, California.
University of California, Division of Soils, 120 Hilgard Hall, Berkeley 4, California.
University of California at Los Angeles, The Library, 405 Hilgard Avenue, Los Angeles 24, California.
University of California Warehouse, 2219 W. Pico Boulevard, Los Angeles 6, California.
University of Cape Town, J. W. Jagger Library, Rondebosch, Cape Town, South Africa.
University of Chattanooga Library, Chattanooga, Tennessee.
University of Chicago Libraries, Periodical Division, Harper M 26, Chicago, Illinois.

University of Cincinnati, Mr. Peter Scherrer, Director of Central Stores, Cincinnati 21, Ohio.
University of Cincinnati, The General Library, Cincinnati 21, Ohio.
University of Colorado Library, Boulder, Colorado.
University of Connecticut Library, Storrs, Connecticut.
University of Georgia, General Library, Serials Division, Athens, Georgia.
University of Hawaii, Library, Honolulu, Hawaii.
University of Illinois Library, Urbana, Illinois.
University of Kansas Library, Periodical Dept., Lawrence, Kansas.
University of Kentucky Library, Lexington 29, Kentucky.
University of Leeds, Leeds, Yorkshire, England.
University of Manchester Library, Manchester, England.
University of Manitoba, Science Library, Winnipeg, Manitoba, Canada.
University of Melbourne, Central Library, Carlton N 3, Victoria, Australia.
University of Michigan, General Library, Ann Arbor, Michigan.
University of Minnesota Library, Minnespolis 14, Minnesota.
University of Missouri General Library, Columbia, Missouri.
University of Montreal, Dept. of Geology, 2900 Mount Royal Boulevard, Montreal, Canada.
University of Nebraska Libraries, Lincoln 8, Nebraska.
University of Nevada Library, Reno, Nevada.
University of New Hampshire, Hamilton Smith Library, Durham, New Hampshire.
University of New Mexico Library, Albuquerque, New Mexico.
University of North Carolina Library, Chapel Hill, North Carolina.
University of Oklahoma Library, Norman, Oklahoma.
University of Oregon Library, Eugene, Oregon.
University of Otago, Librarian, Dunedin N 1, New Zealand.
University of Pennsylvania Library, Philadelphia, Pennsylvania.
University of Pittsburgh, University Library, Room 530, Cathedral of Learning, Pittsburgh, Pennsylvania.
University of Pretoria, Librarian, Pretoria, South Africa.
University of Queensland, Library, Brisbane, Queensland, Australia.
University of Rochester Library, Rochester, New York.
University of St. Andrews Library, St. Andrews, Scotland.
University of Sheffield, Applied Science Library, St. George's Square, Sheffield 1, England.
University of South Dakota Library, Vermilion, South Dakota.
University of Southern California Library, University Park, Los Angeles, California.
University of Stockholm, Mineralogical Department, Drottninggatan 116, Stockholm, Sweden.
University of Sydney, Fisher Library, Sydney, New South Wales, Australia.
University of Tennessee, Library, Knoxville 16, Tennessee.
University of Texas, Library, Serials Acquisition, Austin, Texas.
University of Toronto, Library, Toronto 5, Ontario, Canada.
University of Utah Library, Salt Lake City, Utah.
University of Virginia, Alderman Library, Charlottesville, Virginia.
University of Washington Library, Seattle, Washington.
University of Washington, College of Mines, 324 Mines Laboratory, Seattle, Washington.
University of West Virginia Library, Morgantown, West Virginia.
University of Western Australia, The Librarian, Perth, Western Australia.
University of Wisconsin, Periodicals Division, General Library, Madison 6, Wisconsin.

University of the Witwatersrand, Main Library, Milner Park, Johannesburg, South Africa.
University of Wyoming Library, Laramie, Wyoming.

Valentin Garcia y Cia, Apartado 2103, Habana, Cuba.
Vanadium Corporation of America Library, Bridgeville, Pennsylvania.
Vanderbilt University, Joint University Library, Nashville, Tennessee.
Victory Shipping Company, Inc., Maritime Building, 8–10 Bridge Street, New Uork, New York. (For Wennergren-Williams, Kungl. Vetenskapsakademiens Bibliotek).
Virginia Military Institute, Library, Lexington, Virginia.
Vyas & Company, Amraoti, Berar, India.

Ward's Natural Science Establishment, 3000 Ridge Road East, Rochester, New York.
Washington State College Library, W. W. Foote, Librarian, Pullman, Washington.
Washington University Library, St. Louis, Missouri.
Wayne Laboratories, 17 East Main Street, Waynesboro, Pennsylvania.
Wellesley College Library, Wellesley 81, Massachusetts.
Wesleyan College Library, 175 North Street, Middletown, Connecticut.
Western Australia Government Stores Department, Controller of Stores, Fremantle, Western Australia.
Wichita City Library, Wichita, Kansas.
Willamette University Library, Salem, Oregon.

Young, Henry, and Sons, Ltd., 15 North John Street, Liverpool, England.

NOTES AND NEWS

MINERALS FOR DESTROYED MUSEUMS

The Continental Committee wishes to urge all Local Committees and every mineralogist to contribute minerals at the earliest possible date. Shipments are now being prepared for the following museums: (1) Liége, Belgium; (2) Kiev, Ukraine; (3) Caen, France; (4) Prague, Czechoslovakia; (5) Brussels, Belgium. They should be ready by the end of May 1946. Please indicate for which museum each package is intended. Ship in separate containers gifts for different institutions. For detailed instructions, please refer to the original appeal (*Am. Mineral.*, **30**, 538–40, 1945, July-August issue).

Charles Palache, *Chairman.*
J. D. H. Donnay, *Secretary.*

Dr. Bennett Frank Buie has been appointed Professor of Geology and Mineralogy at the University of South Carolina, Columbia, South Carolina. Dr. Buie was recently released from the Army where he had served as a Major in the Corps of Engineers attached to the Persian Gulf Command.

The Department of Geology of the University of South Carolina has recently acquired the Colburn Mineral Collection. This collection is well known to mineralogists as it is especially rich in rare and beautiful minerals from the Southern Appalachians.

The Pennsylvania State College has recently issued Circular 20 entitled "Opportunities for Productive Work through Mineral Industries Research." This interesting and instructive 36 page pamphlet can be obtained free of charge by writing A. W. Gauger, Director, Mineral Industries Experiment Station, State College, Pennsylvania.

Meetings of The New York Mineralogical Club, Inc., were held in January and February. At the January meeting Dr. Lester Stroeck spoke on "The Applications of Spectroscopy in Economic Geology," and pointed out how this method assisted in the discovery of a large deposit of the rare beryllium mineral helvite.

At the February meeting it was announced that Professor Kerr would edit Mr. Trainor's paper on the Minerals of Tilly Foster for publication by the Club. At the same meeting Dr. E. Jacobs of the University of Vermont and State Geologist spoke on the minerals of that State. Some of the unusual localities mentioned were Mt. Mansfield, South Strafford and Mt. Belvidere.

Teaching Assistantship in Mineralogy and Geology

A half-time teaching assistantship in mineralogy and geology is available at Missouri School of Mines and Metallurgy, to a student who, having the equivalent of a B.S. degree, becomes a candidate for the M.S. degree at this institution. The student may register for 12 credit hours each semester, a minimum of 36 credit hours being required for the Master's degree. The assistantship pays $675 for the School year of nine months. Tuition fees amount to approximately $60.

Applications, supported by letters of recommendation, should be addressed to Dean Curtis L. Wilson, Missouri School of Mines and Metallurgy, Rolla, Missouri.